

Effect of nitrogen sources, sulphur and boron levels on sunflower-mungbean cropping system

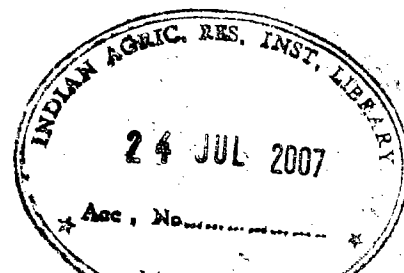
सूरजमुखी-मूँगबीन फसल प्रणाली पर नाइट्रोजन स्रोतों, सल्फर तथा बोरॉन स्तरों का प्रभाव

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INDIAN AGRICULTURAL RESEARCH INSTITUTE
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Effect of nitrogen sources, sulphur and boron levels on sunflower-mungbean cropping system

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KAPILA SHEKHAWAT

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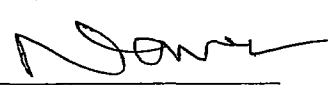
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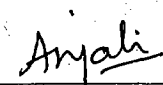
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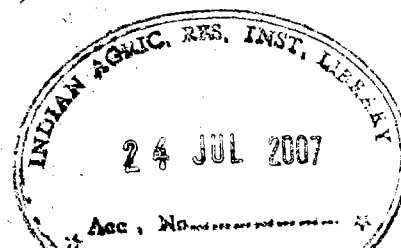
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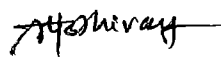
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This is to certify that the thesis entitled "**Effect of nitrogen sources, sulphur and boron levels on sunflower-mungbean cropping system**" submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy in Agronomy**, embodies the results of *bona fide* research work carried out by **Ms. Kapila Shekhawat** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

All the assistance and help received during the course of the investigation have been duly acknowledged by her.

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is a non-traditional oilseed crop introduced in India during the year 1969, it now occupies an important place in all agro-climatic zones. Sunflower holds great promise because of its short duration, photo-insensitivity and wide adaptability to different agro-climatic regions and soils types. It can be grown at any time of the year and can serve as an ideal catch crop during the period when the land is otherwise fallow. Spring sunflower best suits such conditions with chances of area expansion and horizontal intensification for enhancing oilseed production in India.

The shortage of edible oils has become a chronic problem in India with increasing demographic pressure. Sunflower can play an important role in meeting out shortage of edible oils in the country. It covers an area around 3.2 million hectares and 1.85 million tonnes of total production with 616 kg/ha average productivity (FAI, 2006). The existing yield is very low in India, mainly because of the sub-optimal soil fertility. There is ample scope of increasing production by use of agronomic as well as proper fertility management. A suitable combination of major and micronutrients is by and large the most important single factor that affects the yield and quality of sunflower.

Sunflower is a heavy feeder of nutrient and is an exhaustive crop. Sunflower crop with an average yield of 1500 kg/ha removes 100 kg N/ha, 15 kg P₂O₅ and 150 kg K₂O/ha. It was found to respond to N up to 80 kg N/ha, P up to 60 kg/ha and K up to 50 kg/ha (Sadiq *et al.*, 2000).

S being an element of utmost importance for sunflower has dragged the attention of research workers. It has many fold advantages regarding growth parameters, yield and quality as well. Ramu and Reddy (2003) showed that N and S application significantly increased the plant height, leaf area and dry matter production

in sunflower. Application of 100 kg N + 40 kg S/ha recorded significantly higher head diameter, filled seeds per head and test weight. Similarly Maity *et al.* (2003) revealed that growth parameters such as leaf area index (LAI), net assimilation rate (NAR) and total dry matter accumulation increased with increased S rates. Seed yield and S uptake were increased by S application. Seed oil content was higher with S dose @ 20 kg/ha as mentioned by Sreemannarayan *et al.* (1994).

Likewise B has many important roles like flowering, fruiting processes, pollen germination and hence seed setting also. Tamak *et al.* (1997) reported that seed yield of sunflower was significantly higher with 25 kg S/ha and foliar application of B. These elements have positive effect on seed yield and quality. Vasudevan *et al.* (1997) concluded that the highest yield of sunflower was obtained with the combination of recommended N and S + borax dusting. B also improves the seed quality parameters such as higher germination, higher speed of germination, higher shoot and root length, higher vigour index and seedling growth rate. The yield increase owe to improvement in growth and yield components, viz. LAI, filled seeds/head and test weight. Thomas *et al.* (2004) also found significant correlation between B and shoot weight and mean leaf fresh weight.

S is an essential constituent of many proteins, enzymes and certain volatile compounds in poly unsaturated fatty acid (PUFA) in sunflower. S application significantly improved quality of sunflower oil in terms of free fatty acid, iodine value, lower saturated fatty acids like stearic and palmitic acids and higher PUFA like linoleic and oleic acids (Krishnamurthy and Mathan, 1996). Rattan *et al.* (1995) studied the effect of S on the uptake of other nutrients and found synergistic effect between S and N, S and P and S and Zn, hence maintains overall soil nutrient balance.

Since the fertilizer applied to one crop exhibit residual effect on succeeding crop, fertilization must be done keeping the whole cropping system in view rather than the individual crops. Hence the residual effect of fertilizers on succeeding mungbean crop was studied. Since sunflower is an exhaustive crop, mungbean in the sequence is a good choice as it helps in building up the nutrient status of soil being a leguminous crop.

The influence of both S and B is so intense in growth and development of sunflower that it has gained due prominence in research. This research requires tools and techniques that can facilitate the integration and utilization of inter-disciplinary knowledge in solving agricultural problem at field, farm regional scales and thus increase the efficiency of agricultural research. On farm decision support tools based on system simulation are such tools which assist farmers and extension workers in making strategic decisions like choice of crop, variety, nutrient doses and their interactions as well as amount and time of fertilizer application. To address these issues, InfoCrop – a generic crop model based on Decision Support System (DSS) has been developed at IARI. This model has focused on determining potential yields of cultivars of different crops in various agroclimatic regions (Aggarwal *et al.*, 1996 and Pathak *et al.*, 2003). So the present study entitled “**Effect of N sources, S and B levels on sunflower-mungbean cropping system**” has been framed to apply such dynamic crop model in problem solving efforts with following objectives:

1. To study the effect of N sources, S and B levels on productivity and quality of spring sunflower-mungbean cropping system;
2. To develop production functions for optimizing N sources and doses of S and B for maximizing productivity;
3. To develop a dynamic sub-routine for assessing growth and yield of spring sunflower and mungbean at varying inputs of N, S and B.

REVIEW OF LITERATURE

The shortage of edible oil has become a chronic problem for India with increasing population and the vegetable oil consumption is both price and income elastic. Sunflower can play an important role in reducing shortage of edible oils due to its good oil recovery up to 40%. Since it is a non-traditional crop, cultivation of sunflower as an oilseed is not an age old in India. Being an introduced crop in India, the previous work done pertaining to efficient and judicious nutrient management, especially with reference to micronutrients is scanty. A suitable combination of major and micronutrients is by and large the most important single factor that affects the yield and quality of sunflower crop. Since the fertilizers applied to one crop exhibit residual effect on succeeding crop, fertilization must be done keeping the whole cropping system in view rather than the individual crop, hence spring sunflower-mungbean cropping system has been selected. In this context, the available literature on nutrient management of sunflower and residual effect of nutrient application on mungbean and available soil nutrient status is reviewed hereunder.

2.1 SUNFLOWER

2.1.1 Effect of nitrogen on growth

N plays a very important role in crop production. The appropriate rate of N promotes fast vigorous growth and high yields. For sunflower, use of proper rate is very important which depends upon soil type, season and cropping system as well.

Reports from Tenebe *et al.* (1996) showed increase in leaf area index, shoot dry weight and seed yield with increasing N rates from 0-100 kg/ha, but beyond this, growth started to decline. Similar results were obtained by Rani and Reddy (1993) that plant height, stem girth, number of leaves/plant and dry matter production were the highest with application of N @ 120 kg/ha.

Plant growth is simultaneously subjected to genetic, ontogenetic environmental control. Mishra *et al.* (1995) recorded significant increase in dry matter accumulation of sunflower with application of 60 kg N/ha. The study of the crop to dry matter accumulation is important for determination of a better agronomic management. Total dry matter accumulation trend, using growth adopted function parameters helps in understanding the relations between agronomic and environmental factors and crop yield.

Kasem and El Mesilchy (1992) reported that increasing doses of N (0 to 60 kg/ha) delayed the flowering but increased leaf area, number of green leaves per plant, plant height, stem diameter and head diameter. The results of experiment by Mrinalini *et al.* (1998) revealed that at the flowering and maturity stages, the increase in dry matter accumulation with the progressive increase in N levels up to 100 kg N/ha were significant.

N application helps the plant in making quick growth and vigorous development in terms of root and shoots dry weight. Ayub *et al.* (1998) reported maximum plant height, leaves per plant and stem diameter due to N application.

Once the growth is triggered to secure future development, carbon assimilating portion (shoot) and mineral acquiring portion (root) tissue must continuously be balanced both in relation to each other and in relation to resource supplied. Hence dry matter partitioning is equally important as total dry matter accumulation is considered. Gazelius and Nasholm (1993) found that low N-seedling grew more slowly and had high root/shoot ratios than high N-seedling. Under N deficient condition, more nutrients drive towards roots resulting in poor shoot growth. With respect to total N, the effect of the lower nutrient supply was mainly on the nitrogen content of the whole plant. Hence, above ground parts are adversely affected.

In another study by Dale *et al.* (1991), reported that roots appeared healthy where N was supplied. Roots were having less branches, thinner and were shorter when N was deficient which reduces the total root dry weight.

Sinclair and Horie (1989) concluded that N supply strongly influences crop growth through its effect on leaf area development and photosynthetic capacity.

Variation in leaf carbon-dioxide exchange rate (CER) is strongly associated with leaf N content.

Tonev (2006) reported that the direct N fertilization had a positive linear effect on the leaf area increase on the crop till the period of intensive growth (budding) when the roots of sunflower settled under 1 m soil layer and direct N fertilization become significant for sunflower growth. Direct N fertilization affected positively the biological productivity at budding stage. A tendency was registered towards increase of the relative share of stems at the expense of other vegetative organs (leaves, petioles) with N fertilization.

Various growth parameters like LAI, CGR, RGR and NAR are dependent upon the total and relative dry matter accumulation per plant. Higher the rate of dry matter accumulation, higher will be these parameters. Mandal (2000) reported that N applied @ 80 kg/ha significantly improved growth attributes. Legha and Giri (1999) reported that N application enhanced plant height, leaf area and total dry matter accumulation. They also reported that CGR increased up to 60 DAS and declined thereafter, RGR declined continuously till later growth stages whereas NAR followed the similar pattern like RGR, according to relative additions to the base dry matter of the plant.

Hirose (1984) revealed that N availability influenced the N uptake of plant through the uptake rate per unit root weight rather than the amount of root. In turn, the different amounts of N taken up affected plant growth through their effects on leaf area expansion and hence NAR increased with increasing doses of N.

N is an essential constituent of chlorophyll and imparts green colour to the leaves. Singh *et al.* (1998) recorded that chlorophyll meter reading increased with increasing N application. These results were in line with Shaktawat and Bansal (1999), Edara and Patel (2000) and Malewar *et al.* (1999).

N can be supplied through various sources. Ammonical and nitrate are the two types of fertilizers available whose selection affects various growth phases in crop. Silveira *et al.* (2007) concluded that selection of N sources should be carefully planned to avoid detrimental effects on soil quality and consequently fertilizer use-efficiency.

Ammonium N uptake alters the plant sugar metabolism. This encourages more sugar production and greater rate of export out of the leaves to the roots and on the

way to the roots, fruits and storage organ can grab the sugar and enhance growth, yield and quality and decrease the susceptibility to diseases. If plant can utilize 50% of their N as ammonical forms the crop can produce more yield with the same N level. Whereas nitrate-N tends to accumulate in the leaves and increase organic acid production, which increases the demand for calcium to neutralize the acidity, if this calcium is in short supply calcium may be remobilized from the roots. This movement of calcium from the roots disturbs root integrity and can lead to leaky roots and ethylene production, signaling the plant to shut down. Because of the above-mentioned metabolic and physiological phenomenon as reported by Atkin and Cummins (1994), there could be a possible variation in growth when N is supplied through urea or CAN. Comparing the effect of different N sources, Christorsson (1972) found that the growth of pine seedlings was lower with urea than with ammonical sources. The lower growth rate and the chlorosis of urea-fed seedlings were suggested to be the result of a hydrolysis of urea inside the root, causing an increase in pH and an accumulation of ammonia in the root.

2.1.2 Effect of N on yield attributes and yield

N earns its place of prominence in our thinking as N is the key element in the realization of the yield potential of both modern day and traditional agriculture. Mandal and Sinha (2004) studied the effect of N management on light interception, photosynthesis, growth, biomass production and yield. They concluded that 1000-seed weight, seed and stover yield increased with increasing N doses.

Bindra and Kharwara (1992) obtained significant increase in yield attributes and yield (seed as well as oil) up to the N level of 60 kg/ha. But Sarkar *et al.* (1995) could notice appreciable improvement in yield attributes and yield with increase in N level up to 80 kg/ha.

The higher availability of nutrients especially N in the initial stage helped to acquire a definite advantage over other treatments in respect of growth. Better partitioning of photosynthates from source to sink leads to higher yield attributing characters which finally results into higher yield of sunflower. Rao and Saran (1991) reported that seed yield, head diameter, seeds per capitulum and 1000-seed weight

increased significantly with application of N, the highest seed and stalk yield were being at a N dose of 80 kg/ha.

Pal *et al.* (1996) recorded that the yield at 100 kg N/ha was at par with 80 kg N/ha. Observable increase were there in head diameter, seed weight per plant, 1000-seed weight as well as biological yield with increased N rates.

Sharma *et al.* (1995) revealed that the performance of CAN and urea was at par in terms of yield but the apparent recovery of N by potato tubers was higher with CAN than with urea.

2.1.3 Effect of N on oil content and quality

N is essential not only for vegetative growth but also to improve the seed size, its proper filling and to increase oil content. Therefore, it is necessary to add adequate amount of N fertilizers in the field of sunflower. Hussain *et al.* (1998) concluded that fertilization led to an increase in protein content and reduction in sugar content of the leaves at flowering phase with consequent increase in oil content of seeds. Crops raised from the seed produced with N application developed more rapidly, had a deeper root system, produced more seed weight with higher oil content as compared to the crop without N.

At the same time, high N doses are responsible for the excessive vegetative growth resulting in reduction in oil content of the seed. Satyanarayan^{et al} (1986) found that this might be due to degradation of carbohydrates in tricarboxylic cycle to acetyl CoA, whereby reductive amination and transamination process form more amino acid causing increased seed protein content with corresponding decrease in seed oil content.

Sawan and Hafez (2001) revealed that application of N resulted in increased seed protein content, oil and protein yields/ha. Nakasathin *et al.* (2000) concluded that protein content is a qualitative trait and influenced by environmental and management effects. Whole plant processes such as N acquisition, translocation and mobilization of C and N are important in determination of seed protein concentration. Thus increased N concentration helps in enhanced protein content in seeds and seed protein content can be increased by increasing external N concentration during reproductive growth.

N plays a crucial role in maintaining protein : oil ratio in seed. N fertilization could be advantageous to improve the nutritional value by increasing protein content and maintaining concentration of essential amino acids (Thanapornpoonpong, 2004). He also reported that fertilization increase seed protein and linoleic acid content.

Regarding the effect of N sources on protein content, there are different views of different workers; Venus and Causton (1979) found that presence of NO_3^- in the growth medium of sunflower seedlings increase the level of nitrate reductase and nitrite reductase activities which enhances the N pool in plants while Strong *et al.* (1996) concluded that seed yield and seed protein were not affected by N source. They reported that the interaction between N rate and N product was not significant in any crop and the cause of differences in performance could be due to factors other than form of N.

Sunflower oil has high level of linoleic acid. Linoleic acid is required for the cell membrane structure, cholesterol transportation in the blood and for prolonged blood clotting, sunflower oil helps to reduce the serum cholesterol levels in human beings. Sawan and Hafez (2001) revealed that the higher N rate resulted in an increase in seed oil refractive index, unsaponifiable matter and total unsaturated fatty acid content. However, it decreased the oil acid value, saponification value and total saturated fatty acid content.

2.1.4 Effect of N on nutrient uptake and available soil nutrient status

N application in the form of inorganic fertilizer enhances the content of nitrogen in sunflower. This is because of the poor N status of soil and immediate availability of soluble N to plants. Hiremath *et al.* (1992) stated that application of N was found to increase the N concentration of all the plant parts as compared to no N application. The N concentration of leaf at all growth stages, in stem at 30 and 60 days and in head at 60 days and at harvest increased, with every dose of increase in the N level from 0-100 kg N/ha. These findings were in line with the conclusion of Zayan *et al.* (1989).

Roots are the medium for nutrient absorption and translocation to the above ground parts. Fenelonova (1968) studied the effect of mineral nutrition on absorption ability of roots, growth and productivity of sunflower and found that the soil

application of N @ 40 and 90 kg/ha increased the nutrient absorption ability of the root system by increasing the amount of cell sap in the roots and NO_3^- content of cell sap. Similarly, Cathcart *et al.* (2004) found a high rate of N fertilizer increased corn leaf and grain N content, leaf area index, plant height, above ground dry matter production, including kernel weight.

N application also helps in uptake of other nutrients by plants. Enhanced root growth and soft succulent vegetative terminal growth due to N fertilization helps in better rhizosphere exploration and enhanced growth keep the pace of nutrient uptake high. Biswas *et al.* (1995) found that N application had a synergistic effect on the uptake of P, K, Zn, Cu and Fe. Kumar and Reddy (1997) concluded that N application caused to increase the uptake of both N and S by plant parts and total S removed by sunflower crop. N and S also increased each other's recovery from the fertilizer source by the crop resulting in higher fertilizer use-efficiency.

Sunflower is a heavy feeder of nutrients especially N, giving good response to applied fertilizers. Use of proper N rate in this crop assumed greater significance since higher dose of N may result in excessive vegetative growth at the expense of reproductive growth. Sunflower crop with an average yield of 1.5 tonnes seed, removes about 100 kg N/ha from the soil. N mineralization rate is higher in upper humus layer and upper mineral soil. When NO_3^- -N is applied, it enhances the NO_3^- content in the upper layer. Since the N application is preferred in two splits, its application does not make much change in the deeper layer (Tandon, 1995).

Source of N can cause effect on N available status of soil. Ammonical forms are able to enhance the native status of soil. The ammonium molecule carries positive electrical charge and is attached to soil matrix, hence less exposed to leaching while nitrate fraction remains dissolved in the soil water. Also, the volatilization losses from surface applied ammonical fertilizers like CAN are quite small as compared to urea. Environmental concerns also arise with excessive nitrates which lead to potential leaching to ground water.

2.1.5 Effect of N on economics of crop

The rising energy costs have resulted in increased N fertilizer costs and future global predictions suggest even higher prices are yet to come. N application results in

higher yield, oil and protein content of sunflower. Hence, returns per unit area and per unit rupee invested are very high. Out of the different sources, Murphy *et al.* (2002) concluded that urea was economically better than CAN where more than 20 kg N/ha was applied giving up to an extra 100 \$/ha return. Because the response to different fertilizer N sources is often minimal the relative cost of N source is prime consideration and therefore urea is a universal choice which is usually the best to use unless special circumstances occur since it is three times cheaper than CAN.

2.2.1 Effect of sulphur on growth

Sunflower is considered as a heavy feeder of nutrients, specially sulphur as it is an oilseed crop. Within the genetic limits, higher yield of crops can be realized under favourable crop environment condition with proper soil fertility management. Sunflower requires more S, almost equal to phosphorus.

Ramu and Reddy (2003) showed that S application significantly increased the plant height, leaf area, dry matter production in sunflower. Bhagat *et al.* (2003) also concluded that the highest growth in terms of plant height, number of functional leaves, leaf area, leaf area index and stem girth were recorded with application of 40 kg S/ha. Leaf area index measures the total leaf expansion per unit land area. Maity *et al.* (2003) recorded growth parameters like leaf area index increased due to S application @ 40 kg/ha. The positive correlation between dry matter accumulations with S application was also proved by Badr-ur-Zaman *et al.* (2002). They found that fresh weight, dry matter yield of shoot and root and length of stem and root increased with increasing S doses. The findings of Sreemannarayan and Srinivasa (1993) were also in line with this.

S plays an important role in vegetative growth and its deficiency at vegetative stage cause severe reduction in biomass production. Various growth parameters like CGR, RGR and NAR etc. are the functions of dry matter accumulated by the plant. Reddy and Singh (1996) suggested that the high rate of S gave the highest values of leaf area and dry matter accumulation. Also CGR and NAR were higher at early stages due to sharp increase in dry matter accumulation and quick early growth. Ali *et al.* (1997) concluded that application of S increased root and shoot length. S was efficiently utilized by sunflower crop and the uptake in expanded leaves was higher.

Hence, RGR was higher at initial stages and declined further. Also, S requirement of the crop is more at early stages, its application should be made prior to bud initiation. S is necessary for chlorophyll synthesis. Khurana *et al.* (1998) reported that due to S deficiency leaf becomes pale, young leaves get bleached at apex. Later middle leaves turned pale and chlorotic and the size of the leaf was drastically reduced. Sofi *et al.* (2004) also found that chlorophyll and carotenoid content increased with increasing levels of S.

2.2.2 Effect of S on yield attributes and yield

S plays a vital role in different physiological and biochemical functions in plants. Its deficiency at reproductive stage drastically reduced flowering, prevent anthesis, cause head shattering, reduces seed number and their weight and thereby, their yield and quality (Singh, 2001). Legha and Giri (1999) revealed that S applied @ 30 kg/ha significantly increased the number of seeds and seed weight/capitulum which are important yield attributing characters. Similarly, Reddy (2003) recorded higher head diameter, filled seeds/head and test weight with 40 kg S/ha. S also influenced LAI, seed yield, seed filling (%), volume weight, achne and seeds oil content.

Seed yield of sunflower increased with S application. Sreemannarayan and Raju (1993) showed an increase in seed yield up to 45 kg S/ha. Wani (2002) reported that seed and stover yield, available S status in soil, seed and stover S content and uptake increased with increasing rates of S. These results are in line with the findings of Agarwal *et al.* (2000). Sarkar (1999) reported that response of sunflower seed yield to S applied @ 15, 30, 45 kg/ha was 35, 59, 85%, respectively. Maximum response of S was obtained at application rate of 45 kg S/ha with 15 kg seed yield/kg S applied.

2.2.3 Effect of S on oil content and quality

S helps in biosynthesis of oil. Vegetable oils are triglycerides, glycerol bound to 3 fatty acids. Ahmad and Abdin (2000) showed a strong positive correlation between S and lipid content in the seed. Application of S increased the lipid content in the seeds from the initial stage due to enhanced RNA content. The S deficiency reduces oil content due to degradation of carbohydrate in tricarboxylic cycle to acetyl CoA, as a result there is more reductive amination and transamination which increases free amino acids. Bhagat *et al.* (2003) revealed that with increasing levels of S, there was

significant increase in seed yield, protein and oil content and in protein and oil yields also. These results are in line with the findings of Poonia (2003) which suggested that the protein and oil content were increased significantly up to the application of 25 kg S/ha.

Oil and protein accumulate during maturity at the expense of carbohydrates. Sugars, particularly sucrose and its products are the major precursors in the formation of oil and hence are consumed in the biosynthesis of lipids. Diglycerides and amino acid are the metabolic intermediate in the biosynthetic sequence and lipid and protein formation. Maragathan and Chellamuthu (2000) concluded that sunflower respond positively to S with increased seed and oil yields and seed protein content. Molvig *et al.* (1997) showed that S application results in an increase in methionine content and hence is useful in improving the nutritive value of sunflower crop. It increases the live weight, true protein digestibility, biological value and net protein utilization. That is the reason why Reddy *et al.* (1996) found that oil and protein concentration increased with S application.

Oilseed crops show responses to applied S, the magnitude of response depends upon native S status. The S application also improves the quality of the oil as it helps in the synthesis of sulfadryl protein, isocyanate and sulfo-oxides for aroma in oils. Sulphur is also a constituent of vitamins like thiamine and biotin, iron-sulphur protein ferridoxin, sulphur glycoside and various cozymes. Sunflower oil is rich in polyunsaturated fatty acids (PUFA) which are important for making prostaglandins which regulate many body processes including inflammation and blood clotting. Virupakshappa (1994) showed that with increasing S application amount of unsaturated fatty acids like linoleic and oleic acid increases which is desirable and the content of saturated fatty acids like palmitic and stearic reduces. Oleic acid is desirable not only for enhanced shelf life of the oil but also for deep frying and other industrial purposes.

To test a vegetable oil to see how many double bonds it has or how unsaturated it is, iodine value is introduced to the oil. Karle *et al.* (1995) reported that S application increases oil content, yield and iodine number significantly which is directly an indication of degree of unsaturation of fatty acids.

2.2.4 Effect of S on nutrient uptake and available soil nutrient status

Crops differ in their S requirement, absorption and its utilization capabilities within the plant part. Oilseeds are relatively very susceptible to sulphur stress and their requirement is also higher as compared to cereals and pulses. Agarwal *et al.* (2000) concluded that application of S increased the concentration as well as total uptake of N, P, S by sunflower at different stages of crop growth. Sreemannarayan *et al.* (1993) also found that application of S resulted in increase in uptake of N, K, S, Ca, Zn and B both at flowering and maturity stages of the crop growth. S application had a positive effect on nutrient content and uptake by plants with respect to micronutrients also, as Gangadhar *et al.* (1990) revealed that S application at the rate of 40 kg S/ha enhances SO_4^{2-} -S, Zn, Fe, Mn and B content in leaf and seed.

Tandon (1995) reported that the amount of S absorbed in crops normally ranges between 9-15% of N uptake. For sunflower producing a yield of 2-2.5 t/ha, the average S uptake is 16.8 kg/ha with a 20.2% increase in yield due to S application. The critical S level (%) is 0.24 in sunflower at pre-bloom stage (Tandon, 1991). Since S utilization at maturity stage reduced with increasing S rates, Sreemannarayan and Raju (1993) reported that plant S content at bud, flowering and maturity was high and reduced with plant maturity.

Nabi *et al.* (2006) concluded that cumulative N and S content of sunflower seeds, stem and leaves were significantly increased by N and S application. S transport and accumulation in sunflower seed was also increased with S application. Critical S concentration in 60 days old plant was 0.36%. Maximum total S and N concentration were recorded in leaves and seeds. The relative increase in seed yield was more at higher levels of N and S than that of stem and leaf dry weight.

S deficiency has been found in 41% of soils of the country, particularly in oilseed producing belts (Tewatia, 2006). The type of crop grown and the yield level are important factors in determining the S response. The removal by oilseed-legume system is higher than that of cereal-cereal system. Sreemannarayan and Raju (1994) revealed that in sunflower-greengram cropping system there was heavy depletion of S from the soil. Application of S beyond 20 kg/ha significantly improved sulphate status after the sunflower harvest. While there was significant reduction in organic-S fraction

over its initial status, the total and non sulphate-S fraction showed an increasing trend (Bansal *et al.*, 1995). S application resulted in significantly greater sulphate S left behind in soil. Vasudevan^{et al}(1997) reported that S uptake increased with S application. The ratio of S uptake from native to applied source indicated preferential absorption of soil S at all levels of applied S. The efficiency of soil S absorption was higher at initial crop growth stages.

S application also enhances the uptake of other nutrients. The interaction between N and S is reported to be synergistic, since these two nutrients increase the concentration and uptake of each other in the plant. Arora (1986) concluded that S was found helpful in the absorption and utilization of NO_3^- . It reduces free NO_3^- concentration in plant body to maintain NO_3^- and S ratio <10:1. The behavior of P with S is different. Chatterjee (1999) reported that in sunflower crop, under S deficient condition the accumulation of inorganic-P content increased which indicated that inorganic-P absorbed by the plant was not well utilized in their parts. Hence S helps in utilization of inorganic-P into organic or molecular forms within the plant parts.

2.2.5 Effect of S on economic returns

Use of fertilizer by the farmer for increased crop production depends almost entirely on its economics. This is usually done by reporting response per unit area or per unit nutrient applied. To view about the profitability of fertilizer use, benefit: cost ratio is worked out. S has been proved as an inevitable and indispensable element for oilseed crops like sunflower because of its role in oil synthesis which is the economic part of sunflower. Mersick (1997) revealed that the value of sunflower produced/Re invested in S if calculated, yield increase in sunflower (kg seed per kg S) was 9.4, value of crop (Rs/kg S) was around 110.50 and value cost ratio (VCR) was 30.27. Hence, it is profitable to apply S to the sunflower crop as concluded by Biswas *et al.* (2004) that high crop response to S application was seen in sunflower up to 60%. Across different crops, the agronomic efficiency varied from 6-30 kg S/kg S applied and the apparent S recovery from 2-27%. The residual effect on yield of the succeeding crops varied from 3-81%. The economic return from S fertilizer use is an important aspect and the value cost ratio ranged between 12 and 24. Strategic and judicious use of S fertilizers can enhance the economic returns of the farm. Similarly,

Babu and Hegde (2002) concluded that the direct effect of S on sunflower resulted in significant increase of 34% in seed yield and 44% in oil yield with a sulphur use-efficiency (SUE) of 8 kg seed/kg S at 45 kg S/ha. The residual effect on this succeeding groundnut crop resulted in 21% increase in pod yield. The value cost ratio for direct and residual effects were 17 and 34 with a cropping VCR of 52.

2.3.1 Effect of boron on growth of sunflower

B is an essential element which has received maximum attention over last 15 years. The influence of B is so intense and visible in growth and development of oilseed crops that it has gained due prominence in the research being conducted at different places across the world. Yu and Bell (1998) reported that B addition increased dry matter accumulation and plant height because the primary function of B is related to cell wall formation, since B deficiency first appear at the growing points, B deficient plants remain stunted and do not reach maximum height. McIlrath and John (1964) confirmed the results by their finding that lack of lignification of certain vascular tissues is observed when stem of the plant receiving an adequate supply of B was examined histologically, hence there is a continuous growth of the cell. B fertilization also increased the mean stem diameter and height.

Asad *et al.* (2003) concluded that sunflower is one of the most sensitive crops to low B supply developing characteristics, B deficiency symptoms especially on leaves, stems and reproductive parts. B application helps to increase the dry matter accumulation in roots, shoots and leaves.

Heyes *et al.* (1991) mentioned that many of the functions of B in plants may be due to its regulation of metal containing enzymes. B supply enhances the activity of 6-phosphogluconate and glucose-6-phosphate dehydrogenase resulting in enhanced production of phenols. B application helps in the formation of borate complex with these phenols, which helps to regulate the synthesis of phenol alcohols as precursors of lignin biosynthates. Reduced lignification at early crop growth stages allows the growth of the plant. Hua and Yan (1998) found that the addition of B promoted elongation of epicotyls and hypocotyls, thus increased seedling height and dry weight.

Reddy *et al.* (2002) concluded that B fertilization resulted in the higher leaf, stalk, head and total dry matter accumulation. B fertilization also helps in underground

biomass development and better root system proliferation as revealed by Jesten and Kutschera (1999) that in absence of B, no adventitious roots were formed while in the presence of B, numerous roots developed in the lower part of the hypocotyls. In the absence of B, cell division may occur but no root primordial developed. When B was applied, root primordia rapidly developed into well differentiated adventitious roots that entirely replaced the tap root system of intact seedlings. Osterhuis and Zhao (2006) reported that B deficiency during early growth reduced leaf chlorophyll content, reduced leaf stomatal conductance and net photosynthetic rate and reduced non-structural carbohydrate export from leaf to the fruit. Plant growth and dry matter accumulation were also depressed by B deficiency and because of this unfavourable change in dry matter accumulation and partitioning, crop growth rate (CGR) reduces. Role of B in crop growth enhancement was also justified by Mandal and Sinha (2004) who reported that the rate of photosynthesis increased due to B supply with concomitant increase in photosynthetically active radiation (PAR), internal CO₂ concentration and rate of transpiration and reduction in stomatal resistance. Consequent upon the higher rate of photosynthesis, dry matter accumulation increased. Crop receiving B, maintained higher light interception ratio (LIR), leaf area index (LAI), biomass production, CGR and net assimilation ratio (NAR) that resulted in higher harvest index and seed yield.

Pfefferm *et al.* (1998) revealed that B has a beneficial effect on plasma membrane integrity by stimulating membrane related enzymes and by a structural role for the cell wall thereby preventing damage by free O₂ radicals. Rate of the growth of a plant is higher in initial stage and reduces thereafter. The decrease in relative growth rate (RGR) was mainly due to a decrease in unit leaf rate (ULR) as suggested by Rega and Anza (2003) and Overstreet (2003). Leaf starch concentration of B deficient plants doubled due to poor conductance of carbohydrates. These results indicated that B deficiency depressed photo-assimilate translocation from leaves to fruits which ultimately reduces growth.

Kastori *et al.* (1995) confirmed the role of B in leaf chlorophyll content and photosynthesis also. They also found that the leaf area was reduced under B deficiency as well as the content of chlorophyll in the leaves. The content of analysed sugar and glucose were the highest under B deficient conditions. B deficiency appreciably

decreased photosynthetic oxygen evolution by leaves, the apparent quantum yield and quantum efficiency of PS-II electron transport. The diminished rate of photosynthesis in surface leaves due to B deficiency could be correlated to the diminished efficiency of electron transport and to the increased content of sugar in the leaves. Similarly, Daniel and Chen (1995) concluded that leaf production and expansion are critical developmental processes for plant to establish photosynthetic competency and growth. Variation in growth and productivity of plant is caused largely by the variable rates at which leaves are formed, expand and develop into canopies. They are the primary sites of photosynthesis and the product of their metabolism fuel the growth of the stem, roots, flower, fruit and seed. B concentration promote greater leaf area development and leaf initiation also, which ultimately enhanced radiation use efficiency (RUE).

2.3.2 Effect of B on yield attributes and yield

The B requirement of sunflower during reproductive growth is repeatedly much higher than during vegetative growth. Asad *et al.* (2003) found that under B deficient condition, B application increased the vegetative and reproductive dry matter accumulation of plants by more than 3 folds. B application increased the B concentration in various parts of the plant tops, including that of the capitulum. In another study, Hernandez (2005) reported that sunflower plants grown in B deficient condition had 18% less leaf area, 25% less receptacle area and 33% less shoot dry weight. Capitulum damage was observed in the B deficient plants during floret differentiation, resulting in the onset of surface splits. These splits act as centres of floret primordium differentiation, which develop centrifugally and resulted in aberrant capitula and the development of ray flowers and involucral bracts in abnormal position on the inflorescence due to B deficiency.

Asad *et al.* (2002) reported that sunflower is very sensitive to low B supply. The symptoms of deficiency are often more severe during the reproductive stage due to an enhanced sensitivity during this stage. With the onset of reproductive stage severe B deficiency symptoms develop and growth of sunflower ceased. The critical B concentration (i.e. 90% of maximum shoot dry matter yield) in the youngest opened leaf is 25 mg/kg dry matter in sunflower at 75 days after sowing (DAS).

Cell wall pectins are internalized after muco-de-esterification and cross linking with B. Tip growing pollen tubes, which have increased pectin content in their apical cell walls, all expected to rely on crosslinkings of pectin with B. Therefore, due to B application there is very good growth of tip growing pollen tubes and they do not burst due to membrane integrity which increases the number of filled seeds. Renukadevi *et al.* (2003) also revealed that B nutrition increased the head diameter, number of filled seed and 1000-seed weight. The highest yields were obtained in the soil application treatment at the rate of 2 kg B/ha. Under this treatment, sunflower had 3.6-15.8% and 7.2-18.9% higher seed and stalk yields, respectively. Dube *et al.* (2000) revealed the cause of poor yield attributing characters due to B deficiency, as in B deficient sunflower, the head formation was disturbed due to altered hormone metabolism. The relationship between low B content and hormone level has been suggested to be a secondary effect that may be reflected on differentiation and lignification of various tissues involved in head formation.

Shortage of B often limits the growth and yield of sunflower. To avoid this problem, care should be taken to apply B containing fertilizers. Vyakaranahal (2001) reported that B at 0.1% foliar spray at ray floret stage increased the seed yield by 40%. It also increased the capitulum diameter, number of filled seeds/capitulum, seed set percentage, seed yield/plant, 1000-seed weight, oil content in seed and seedling vigour. Apart from the effect of B on yield, seed and oil content can also be affected by B supply. Gohdhara *et al.* (1990) also found that seed yield and seed oil content of sunflower was increased with B fertilization. B application increased SO_4^{2-} -S, Zn, Fe, Mn and B content of leaves.

Chatterjee *et al.* (2005) concluded that at low B concentration, apart from marked depression in growth at 25 days, basal fading and distortion of young leaves with soaked areas and tissues necrosis occurs. In low B, in sunflower leaves, the content of starch reduced and activity of catalase, peroxidase, acid phosphatase, aldolase and ribonuclease increased with accumulation of sugars (non-reduced, reduced and total) and N fraction (non protein). This reduces protein synthesis due to reduced translocation of sugar, starches, N and P, reduced synthesis of amino acids and protein.

2.3.3 Effect of B on oil content and oil quality

Most plant analysis standards have been derived from the relationship between B concentration and shoot dry matter accumulation. However, for many crops, quality of the harvested product is also depressed by low B, and should be considered in the setting of standard of diagnosis. Crop quality may well be a more sensitive indicator for low soil B than shoot dry matter accumulation. Chatterjee ^{Maitiyal} and ~~k~~ (2000) found that B deficiency results in reduced growth, dry matter accumulation, tissue B content, flower head size and seed weight. B deficient seeds showed a significant reduction in contents of non-reducing sugars, oil and starch. Hence, B is important in production and deposition of reserves in the seed of sunflower.

B influences flowering, pollen germination, fruiting, cell division, water relationship and movement of hormones, N metabolism, and also fat metabolism. Sinha *et al.* (1999) also confirmed the previous studies and revealed that after B application, synthesis and utilization of phenols, cell wall synthesis is reduced which results in subsequent reduced accumulation of phenols. Otherwise, oxidation of these phenols if accumulate generates reactive quinones and free radicals of O₂ which are known to be highly toxic to membrane proteins and lipids. The accumulation of phenols in B deficient sunflower seeds is responsible for affecting the quality, resulting in significant decrease in the oil content of seeds due to indirect involvement of B in fat synthesis. Vasudevan *et al.* (1997) also studied that the highest yield of sunflower was obtained with the combination of recommended N and S with Borax. B improves seed quality parameters such as higher germination, higher speed of germination, higher root and shoot length, higher vigour index and seedling growth rate.

2.3.4 Effect of B on nutrient uptake and available soil nutrient status

Proper cell wall requires a continuous source of B and Warrington (1923) stated for B that "..... It is in some way fixed by the plant and not in a state of circulation". Brown and Hu (1994) reported that the function of B is structural rather than metabolic. The greatest part of B in plant is non-exchangeable and can not be remobilized out much suggesting very tight binding in the cells.

Hening and Brown (1997) showed that the uptake of B is a passive process (non-metabolic). B movement in plant has been related to movement in the xylem or

apoplastic system with little to no phloem movement. Once B has been incorporated into tissues, it can not be remobilized to supply the needs of other plant tissues. Renukadevi *et al.* (2002) concluded that B uptake increased linearly with increasing application. Formation of non-exchangeable B complexes within the cytoplasm and cell wall is a key factor in determining the B uptake by plants. In an another related study, Ferrol *et al.* (1993) concluded that B deficiency inhibit ATP dependent H^+ pumping and ATPase activity in sunflower roots which enhances the active uptake of minerals. Protein leakage was greater in microsomal vesicles isolated from cells grown without B.

Partitioning of B into various plant parts depends upon the species and status of B uptake under different soil types. Santos *et al.* (2003) found that B concentration in the leaves was higher than in the stems or roots. Similarly, Rashid *et al.* (1994) found that the critical B concentration in whole shoot was 57 mg B/kg of dry matter for 4 weeks old sunflower plants. It reduced as the advancement of crop age; it became 28 mg B/kg of dry matter for 8 weeks old plant. The distribution of B within the plant parts is different under B deficient and sufficient conditions. Under B sufficient conditions, leaves are the major pools of B but under B deficient condition, Stavrianakou *et al.* (2006) found that a reversal of B distribution pattern between leaves and roots was observed. Under B deficiency, roots remain the bulk of the limited B reserves whereas the supply of B to the above ground organ is limited. The priority is given to the below ground parts concerning maintenance and growth under B limitation. Therefore, the limited amount of nutrients absorbed from the soil is mostly allocated to the root tissues.

B is involved in calcium metabolism in plant, its uptake and reutilization in plant. It is also involved in uptake of Ca, N, P and other minerals. Lefebvre *et al.* (2002) concluded that the uptake of macronutrients like N, P, K and Na responded positively to the dosage of B applied. The relationship between the elements B and Ca was synergistic, showing as steady accumulation and translocation of Ca as the B dosage increased. Extensive studies of C. akmak *et al.* (1995) have supported the idea that B in plant functions at the membrane integrity level. B deficiency causes impaired membrane functions as its primary effect symptoms of deficiency such as auxin and phenol build up as well as increased RNase activity are secondary manifestations of

the reduced ability of membrane to transport vital nutrients and metabolites. Membrane uptake of a number of nutrients is inhibited by B deficiency like leakage of K^+ from sunflower leaves.

Schon (1990) found that the accumulation of leaf B was accompanied by significant increase in leaf N, P and S. All rates of applied B led to significant increase in seed B. Addition of B surrounding the root cell caused a significant hyperpolarization of root cell membrane. B has an effect on K^+ membrane permeability, it causes increase in K^+ accumulation. Sfredo and Sarruge (1990) reported that B application enhanced the trace elements uptake like Mn, Zn, Fe etc.

B is present in most soils in extremely small quantities. B is primarily made available through soil organic matter and minerals. B is water soluble and therefore it can be leached beyond the root zone. Polat and Bajrakli (2003) reported a slight increase in the available B at lower depths of soil. The requirement of B for different crops may be classified into high, medium and low. The requirement of B is higher for oilseed crops like sunflower. Wrobel (1992) also found that sunflower show good correlation between soil and plant B content and therefore is a suitable indicator crop for B deficiency.

B deficiency is often an unsuspected enemy of crop production, therefore, the studies that determine how changes in properties bring B into available form are important, especially to determine from which form it becomes available to the plant and what changes are necessary to cause redistribution. The mechanism of fixation and release of B from soil is an important factor in B nutrition of plants. Goldberg (1997) concluded that compared with other nutrient elements, the chemistry of B in soils is very simple. B does not go oxidation-reduction reactions or volatilization reactions in the soil. The most important factors which affect the status of soil B are soil reaction, soil texture, soluble-salt concentration, organic matter, exchangeable cations, free $CaCO_3$ and soil moisture.

Sakal and Singh (1995) stated that B is the only non-metal nutrient among the micronutrients and occurs in low concentration in the earth's crust. Generally the coarse textured soils contain less soil B and the irrigated soils contain more B than unirrigated. The amount of available B varies with soil depth also, as reported by

Singh and Nayyar (1999) that amount of water soluble B after prolonged irrigation with B rich water, increased with depth. Well drained soil contains 0.3 mg/kg available B in the surface, which gradually increased to 0.5 mg/kg with depth up to 5 feet. The subsoil is richer than the top in available B content. The critical values of B for deficient and low status are 0.5 and 0.5 to 1 mg B/kg soil respectively. More available B may be noticed in lower depths due to leaching.

2.3.5 Effect of boron on economic returns

Plants require a long list of elements including micronutrients like B for growth and each one is required in different proportions. If any one is in short supply, no matter how abundant the rest are, the plant growth will be restricted. The final economic produce, whether it is seed yield, oil yield or ultimately protein yield, is a function of growth statistics. Higher will be the initial growth, more will be economic returns per unit area and per unit rupee invested. Here comes the role of judicious input supply, as concluded by Reddy *et al.* (2002) that boron fertilization resulted in higher head diameter, number of filled grains per head and seed yield of sunflower. Application of boron with recommended dose of fertilizers recorded 13.5% and 12.3% increase in seed yield and stover/stalk yield, respectively. Similar treatment gave the higher net returns (Rs 17,277/ha) and C:B ratio (1:2.06) as a result of increased yield due to boron application.

Dar (2004) also showed that economic returns increased substantially following increase in economic yields with the application of boron. Boron increased yields by 30-40% over the best-bet option treatment based on recommended doses of fertilizers. Economic analysis showed application of B gave benefit of Rs 26,610 (US \$ 584) and the benefit: cost ratio was up to 1.8, while it was 1.3 for control.

2.4 Crop modeling and simulation

For agricultural production in Indian conditions, there is a greater need today for evolving rational management practices, including efficient use of inputs such as irrigation and nutrients. In such production systems, crop management is more complex, decision-making is difficult and economic returns are relatively smaller, hence an interdisciplinary knowledge and its integration is necessary. Several tools of system research related to computer & I.T.(Information and Technology) are available

which can help in solving agricultural problems. One such tool is crop growth simulation model. These models are based on quantitative understanding of the underlying processes and integrate the effect of soil, weather, crop, pest and management factors on growth and yield (Aggarwal *et al.*, 2004). The main reason for stagnant yields in India is conventional blanket fertilizer recommendation, lower fertilizer use-efficiency and imbalanced use of fertilizers. Estimation of fertilizer requirements based on quantitative approaches can assist in improving yields and increasing nutrient use-efficiency. The QUEFTS (Quantitative Evaluation of Fertility of Tropical Soils) is developed for estimation of N, P and K requirement and fertilizer recommendations for a target yield. The model considers the interactions of N, P, K and climate adjusted during the years 1970 to 1998, across wheat growing environments of India. The required N, P and K accumulation in the plant for 1 tonne wheat grain yield was 23.1, 3.5 and 28.5 kg, respectively, suggesting an average N, P, K ratio in the plant dry matter of about 6.6:1.8:1 (Pathak *et al.*, 2003).

2.4 MUNGBEAN

Mungbean (*Vigna radiata* L.) has a pivotal role in Indian agriculture because it provides a major source of protein to more than half of its predominantly vegetarian population. It is an important short duration crop and to enhance the total pulse production, increased mungbean production is necessary. It thrives well on residual fertility and that is why, it is a suitable crop for various cropping sequences, one of which is spring sunflower-mungbean. Effect of residual fertility has a significant role for succeeding mungbean crop as reviewed here.

2.4.1 Effect of N on growth, yield and available nutrient status of soil

N is the key element for successful crop production. N not only enhances yield but it is also indispensable for growth, development and other vital life processes of the plants. Cuzzuol *et al.* (2002) reported that plants treated with N presented an increase in total growth with higher biomass, more but smaller leaves resulting in higher total leaf area, higher net assimilation rate, specific leaf mass and higher biomass allocation to aerial organs.

Patel *et al.* (1996) also reported significant variation in LAI, CGR, dry matter production and grain yield of mungbean after mustard. These results were in line with

the findings of Roy *et al.* (2003) who showed N rate has a profound effect on leaf area development which serves as a net importer of carbon and translocate the photosynthates to the reproductive parts for higher yields.

Sharma *et al.* (1993) found that mungbean chlorophyll content both a, b and total chlorophyll content, were the greatest with N application along with higher PAR interception and protein content. Increase in seed protein content and protein yield with increasing N rates was also reported by Herridge *et al.* (2005). Ayub *et al.* (1999) concluded that yield and yield components of mungbean were influenced by N levels and yield was 31% higher as compared to control. The increase in seed yield with N application was related to higher number of pods/plant, number of seeds per pod and 1000-grain weight. Protein content is also influenced significantly by N application.

N application helps in the uptake of other nutrients also N uptake (grain, stover and total) and S uptake increased with increasing doses of N. K, Zn, Mo and B uptake also enhanced significantly with increasing levels of N. In another study by Sharma and Sharma (2004), they revealed that with N application N, P, K removal was more in grain and stover, thus uptake followed the same pattern observed in the case of grain and stover yield of mungbean.

Grain legume like mungbean improves soil N status directly *via* mineralization of legume residue N, indirectly through the reduction of fertilizer N immobilization and through the conservation of soil N *via* biological N fixation. Ahmad *et al.* (2001) stated that mungbean contributes to the total pool of N in the soil. N fixed ranged from 26-36 kg/ha depending upon various fertilizers

2.4.2 Effect of S on growth, yield and available soil nutrient status

S requirement of pulses is much higher than cereals as it is a constituent of S containing amino acid i.e. cystine, cysteine and methionine, besides being involved in several metabolic processes. Ramasamy *et al.* (1997) revealed that S application had significant effect on the yield and productivity of pulses. It also enhances net returns and B: C ratio.

Badruddin and Shafiqullah (1998) observed that S application also influences the growth rate and root:shoot ratio in plants. The content of plant protein, chlorophyll and photosynthetic CO₂ fixation may also be affected by S. Lack of S in the plant

environment limits the efficiency of applied N and thus S nutrition is necessary to achieve the maximum utilization of applied N.

Siag and Yadav (2003) also studied the response of mungbean to S rates. They found that the number of pods per plant increased with increasing S rates. Plant height, number of seeds per pod and 1000-seed weight were also influenced positively. Grain yield obtained at basal dose of 20 kg S/ha was 42.9% higher than that of control treatment.

Singh and Ram (1990) observed that S occupy an important place in plant nutrition to improve the quantity and quality of the produce. The supply of S to growing crop has a profound influence on protein synthesis and hence the protein content of the seed.

Studying the effect of S on nutrient uptake, Mishra (2000) reported that application of 40 kg S/ha increased the grain and stover yield significantly. The uptake of N, P, K and S were significantly higher with S application. There was synergistic relationship between P and S at lower levels and become antagonistic at higher levels. Application of S accelerated the absorption of N and affected its concentration significantly in grain and stover. With increasing levels of S application the availability of S in soil also increases resulting in higher concentration in growth medium.

2.4.3 Effect of B on growth, yield and available soil nutrient status

For legumes the main impact of micronutrients may be on account of N fixed. Limitation of symbiotic N fixation decrease current crop production and have equally significant impact on subsequent crops in the rotation due to lower residual soil N levels.

Kushwaha (1999) found application of B improved root dry matter accumulation, shoot dry matter accumulation and also root:shoot ratio. B supply increased mycorrhizal activity and number of nodules as well. B recorded higher values of plant height, branches, pods, grain weight, haulm weight/plant and 1000-seed weight. B also recorded higher values for yield attributing characters.

B deficiency is frequently observed in mungbean. Reproductive growth (flowering, fruit and seed set) is more sensitive to B deficiency than vegetative growth.

Verma and Mishra (1999) concluded that plant height, number of branches/plant, number of leaves/plant and dry matter accumulation/plant were increased with application of B. Number of green leaves/plant at different stages of growth increased significantly by B application. Seed yield/plant and number of pods/plant also increased with B application. Similar increase in yield attributes and yields were also observed by Ratanarat *et al.* (1989).

B is immobile in plants whereas highly mobile in the soil. Thus, its application needs a lot of consideration. Tariq and Mott (2007) reported that the concentration of B in soils and plants not only varies with soil type, plant species and environmental conditions, but also its excess or deficiency may affect plant growth and production. Since, there is a very narrow concentration range between deficiency, sufficiency and toxicity in soil-plant system, its application should be carefully planned and managed.

MATERIALS AND METHODS

The field experiment entitled “Effect of nitrogen sources, sulphur and boron levels on sunflower-mungbean cropping system” was conducted during spring and rainy (*kharif*) seasons of 2005 and 2006. During spring season (February to May) sunflower was grown with different sources of nitrogen and variable doses of S and B. In subsequent rainy season (June to September), mungbean was grown to study the residual effect of the treatments applied to preceding sunflower crop in a sunflower-mungbean cropping system. The details of different experimental methodology adopted and material used during the course of investigations are presented in this chapter.

3.1 Materials

3.1.1. Experimental site and soil

The field trials were carried out in the Top Block 4 C in the year 2005 and in Top Block 4 E in 2006 of the research farm of the Division of Agronomy, IARI, Pusa, New Delhi. Soil samples were taken in each cropping season before the start of the experiment, which were analysed, for their physical and chemical properties of the soil. Results are presented in Table 1.

3.1.2 Climate and weather

The geographical position of Delhi is 28°40'N, 77.1°10'E and 228.6 m above mean sea level. Its climate is semi-arid to sub-tropical with extreme cold and hot situations. The hottest months are May and June with the mean maximum temperatures ranging from 41°C to 44°C, whereas the mean minimum temperature of the coldest months of December and January falls in the range of 2°C and 5°C. The daily maximum and minimum temperature tend to rise from first fortnight of February and maintained the trend till the month of June. The evapotranspiration rate also follows the same pattern of temperature during this period.

Table 1. Soil analysis of the experimental field before starting of the experiment

Mechanical composition of soil			
Constituent of soil	Depth of soil (cm)		
	0-30	30-60	60-90
Sand (%)	58.20	62.71	63.14
Silt (%)	14.15	11.13	13.82
Clay (%)	27.65	26.16	23.04

(Hydrometer method – Bouyoucos, 1962)

Physical constants of soil				
Soil characteristics	Depth of soil (cm)			Methods followed
	0-30	30-60	60-90	
Bulk density (g/cc)	1.50	1.52	1.55	Core sampler method (Piper, 1967)
Field capacity (%)	19.12	19.52	19.45	Field method (Coleman, 1944)
Permanent wilting point (%)	6.52	7.52	7.22	Pressure membrane method (Richards (1947)

Chemical properties of soil			
Property	Content		Method employed
	2005	2006	
Organic carbon (%)	0.42	0.42	Walkley and Black (1934)
Electrical conductivity (µS/m)	0.29	0.29	Richards (1954)
pH (1:2.5 soil:water suspension)	7.3	7.4	Blackman's Xeromatic pH meter (Jackson, 1958)
Available N (kg/ha)	166.21	188.27	Alkali permanganate method
Available P ₂ O ₅ (kg/ha)	16.42	15.13	Olsen's method (Olsen <i>et al.</i> , 1954)
Available K ₂ O (kg/ha)	251.36	245.19	Flame photometer R method (Stanford and English, 1956)
Available S (kg/ha)	24.51	22.52	Turbidimetric method (Williams and Steinberg, 1959)
Available B (mg/kg)	0.98	0.96	Hot-water method (Singh <i>et al.</i> , 1999)

Average normal annual rainfall of Delhi is about 650 mm, 74% of which is received during south-west monsoon. July and August are the wettest months of the year. The relative humidity increases from June to September. The mean annual evaporation of this place is about 850 mm. The meteorological data for the two cropping seasons for both the years, as recorded at the meteorological observatory of Indian Agricultural Research Institute, New Delhi are graphically presented in Fig. 1 and Fig. 2. The details of the data are given in Table 2a and 2b.

3.1.3 Cropping history of the field

The crops grown in the experimental field before the commencement of the experiment and also for the period of experimentation are given in Table 3.

Table 3. Cropping history of the experimental field

Year	Field					
	Top block 4 C			Top block 4 E		
	<i>Kharif</i>	<i>Rabi</i>	Spring	<i>Kharif</i>	<i>Rabi</i>	Spring
2003-04	Pearlmillet	Wheat	Fallow	Mungbean	Wheat	Fallow
2004-05	Maize	Fallow	Sunflower*	Pearlmillet	Wheat	Fallow
2005-06	Mungbean*	Wheat	Fallow	Mungbean	Fallow	Sunflower*
2006-07	Pearlmillet	Wheat	Fallow	Mungbean*	Wheat	Fallow

* Experimental crop

3.2 Methods

3.2.1 Details of experiment

3.2.1.1 Layout of experiment

The experiment was laid out in Factorial Randomized Block Design (RRBD) with three replications. There were two sources of nitrogen, three levels each of S and B, hence there were total 18 treatment combinations and one absolute control. The layout plan is given in Fig. 3.

3.2.1.2 Treatments

(A) Sources of N : N applied @ 80 kg/ha

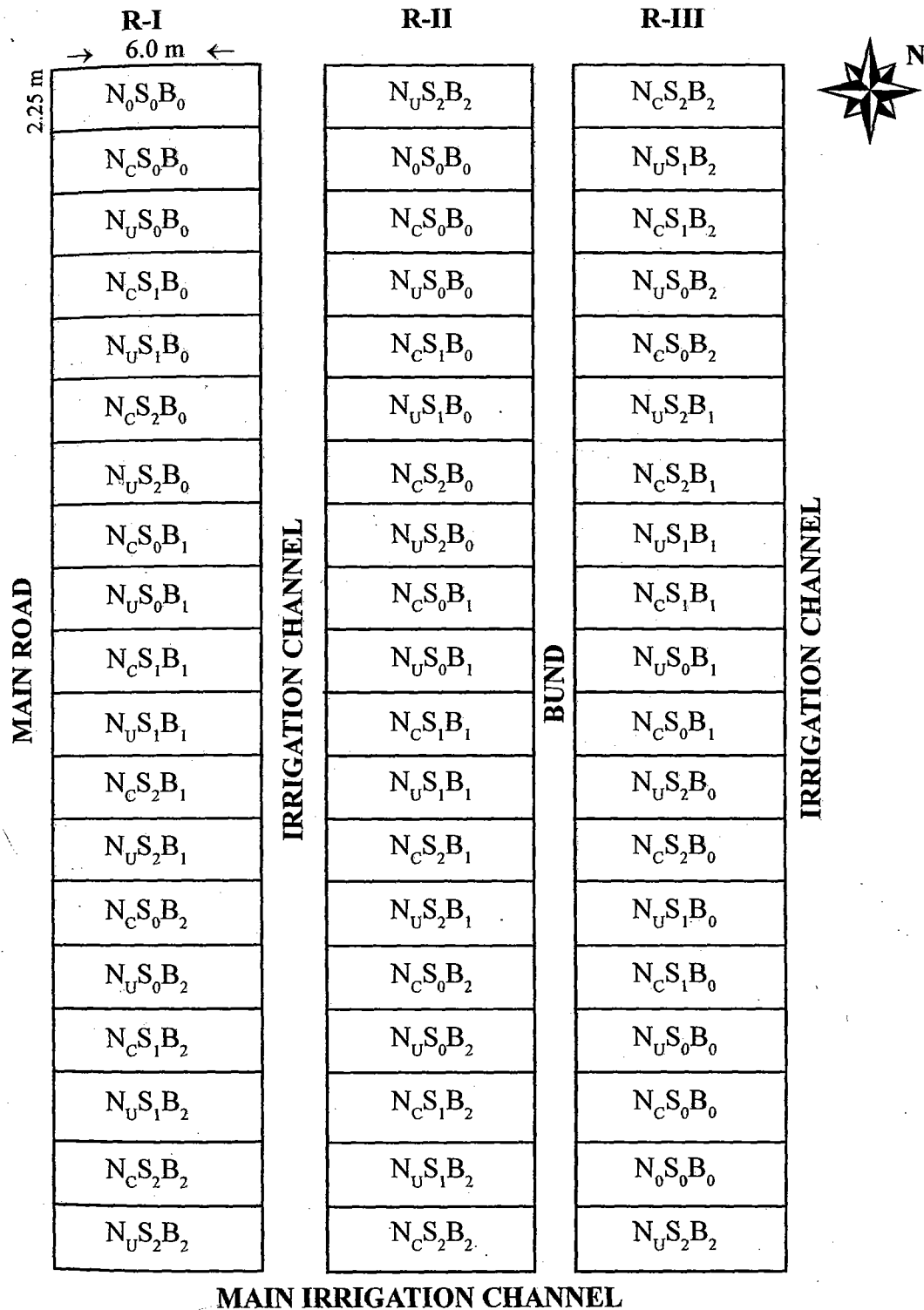
- (1) Urea (It is an organic fertilizer which is used and produced maximum in India among various nitrogenous fertilizers. It is white crystalline salt containing about 44-46% N, an amount greater than that found in any other commercial solid fertilizer. In form of prills, the material is passed by IS sieve 200 and not less than 80% by weight of it shall be retained on IS sieve 100. Per unit kg N from urea costs Rs 10).
- (2) Calcium ammonium nitrate (CAN) (It is dust free, easy flowing granular form containing 25% N. It contains equal amount of ammonical and nitrate form of

Table 2 a. Weekly meteorological data for the crop season (Spring and Kharif, 2005)

Week	Max. temp (°C)	Min. temp (°C)	R.H. (%) (Max.)	Wind velocity (km/hr)	Evaporation (mm)	Total rainfall (mm)	Sunshine hrs. (hrs/day)
6	20.80	9.70	38.20	4.20	4.20	0.00	9.20
7	22.20	10.30	40.30	6.70	3.10	0.00	8.60
8	24.70	10.80	41.50	5.30	5.10	7.20	9.00
9	27.30	11.70	40.20	6.90	4.40	0.00	9.10
10	27.00	12.00	52.00	6.20	5.20	0.00	8.20
11	29.10	12.00	50.00	5.50	4.50	8.70	7.40
12	33.80	13.40	51.00	5.70	6.40	0.00	9.30
13	33.90	16.90	43.00	8.70	6.20	0.00	8.70
14	35.90	17.70	40.70	5.40	7.10	14.30	7.20
15	36.50	19.00	39.50	5.30	11.40	0.00	8.90
16	40.60	24.20	41.00	5.70	7.30	0.00	6.10
17	40.00	24.20	41.20	8.20	6.70	0.00	7.60
18	39.40	22.80	43.70	6.30	8.20	16.80	7.50
19	43.00	28.00	32.50	9.70	7.10	0.00	7.40
20	36.90	28.10	38.00	8.10	11.50	0.00	4.80
21	41.00	25.30	42.50	8.20	6.40	0.00	5.20
22	34.40	22.40	61.00	9.40	5.30	0.00	6.50
23	40.00	30.40	45.50	6.20	5.20	97.60	7.60
24	41.50	29.80	51.20	9.70	8.10	0.00	5.10
25	46.30	31.20	63.70	8.10	8.40	2.80	7.20
26	36.20	29.50	53.10	8.30	4.30	34.00	5.40
27	39.40	30.00	54.20	10.70	7.20	0.00	5.60
28	40.50	31.50	41.70	12.10	8.40	49.60	6.20
29	39.70	29.60	51.10	9.80	8.50	0.00	6.10
30	38.20	29.90	51.40	11.30	7.60	14.80	3.40
31	36.70	28.40	67.50	6.20	6.20	1.50	2.30
32	35.20	27.70	74.20	5.90	5.10	2.00	2.10
33	32.30	26.90	76.70	3.10	4.40	49.60	2.20
34	34.10	26.80	71.10	6.50	5.30	1.40	5.70

Table 2 b. Weekly meteorological data for the crop season (Spring and Kharif, 2006)

Week	Max. temp (°C)	Min. temp (°C)	R.H. (%)	Wind velocity (km/hr)	Evaporation (mm)	Total rainfall (mm)	Sunshine hrs. (hrs/day)
10.00	22.80	9.70	35.20	2.30	2.10	0.00	7.20
11.00	27.70	10.40	62.90	4.20	2.40	0.00	8.10
12.00	29.10	13.40	50.10	5.10	2.30	0.00	7.70
13.00	31.40	15.70	51.30	5.80	3.50	0.00	6.90
14.00	28.20	10.20	52.40	5.50	4.70	0.00	8.80
15.00	25.50	17.70	73.50	2.40	4.20	16.50	5.10
16.00	30.30	12.10	60.70	3.30	6.80	1.20	8.50
17.00	32.90	18.40	54.30	3.20	5.10	0.00	6.40
18.00	35.10	16.30	54.20	2.10	7.40	0.00	8.30
19.00	37.40	20.50	57.10	4.70	8.30	0.00	7.20
20.00	33.30	23.90	78.40	3.80	8.20	12.70	7.10
21.00	39.50	24.20	63.20	4.30	7.50	2.30	8.40
22.00	41.60	25.10	57.20	2.20	9.70	0.00	7.50
23.00	39.80	27.40	79.70	1.10	8.10	17.20	5.60
24.00	33.90	26.70	82.30	3.40	11.20	23.20	7.70
25.00	39.20	28.30	86.50	6.50	3.80	48.20	3.90
26.00	38.10	28.20	69.60	7.30	7.30	0.00	8.20
27.00	43.10	26.40	34.10	5.10	10.40	0.00	8.10
28.00	43.40	31.50	40.40	7.20	11.50	2.30	3.40
29.00	42.50	39.70	47.30	5.70	10.60	0.00	5.60
30.00	35.70	26.90	70.20	3.30	5.10	28.40	3.80
31.00	33.90	26.80	59.90	2.00	3.20	82.30	8.70
32.00	29.50	25.10	76.70	4.20	1.40	66.20	3.30
33.00	34.20	26.30	84.50	2.10	3.30	7.80	4.20
34.00	31.40	25.70	76.30	1.70	2.50	94.10	3.50
35.00	33.10	26.20	75.40	1.90	7.70	4.60	6.40
36.00	32.30	26.20	74.10	1.70	3.10	7.90	4.10
37.00	34.20	25.30	76.80	2.10	2.50	94.70	3.30
38.00	33.70	27.70	79.30	1.60	3.40	4.10	6.20
39.00	33.90	26.10	74.70	2.50	2.30	10.50	5.90



TREATMENT DETAILS

Nitrogen sources

N_U = Urea

N_C = CAN

Levels of sulphur

S_0 = 0 kg/ha

S_1 = 25 kg/ha

S_2 = 50 kg/ha

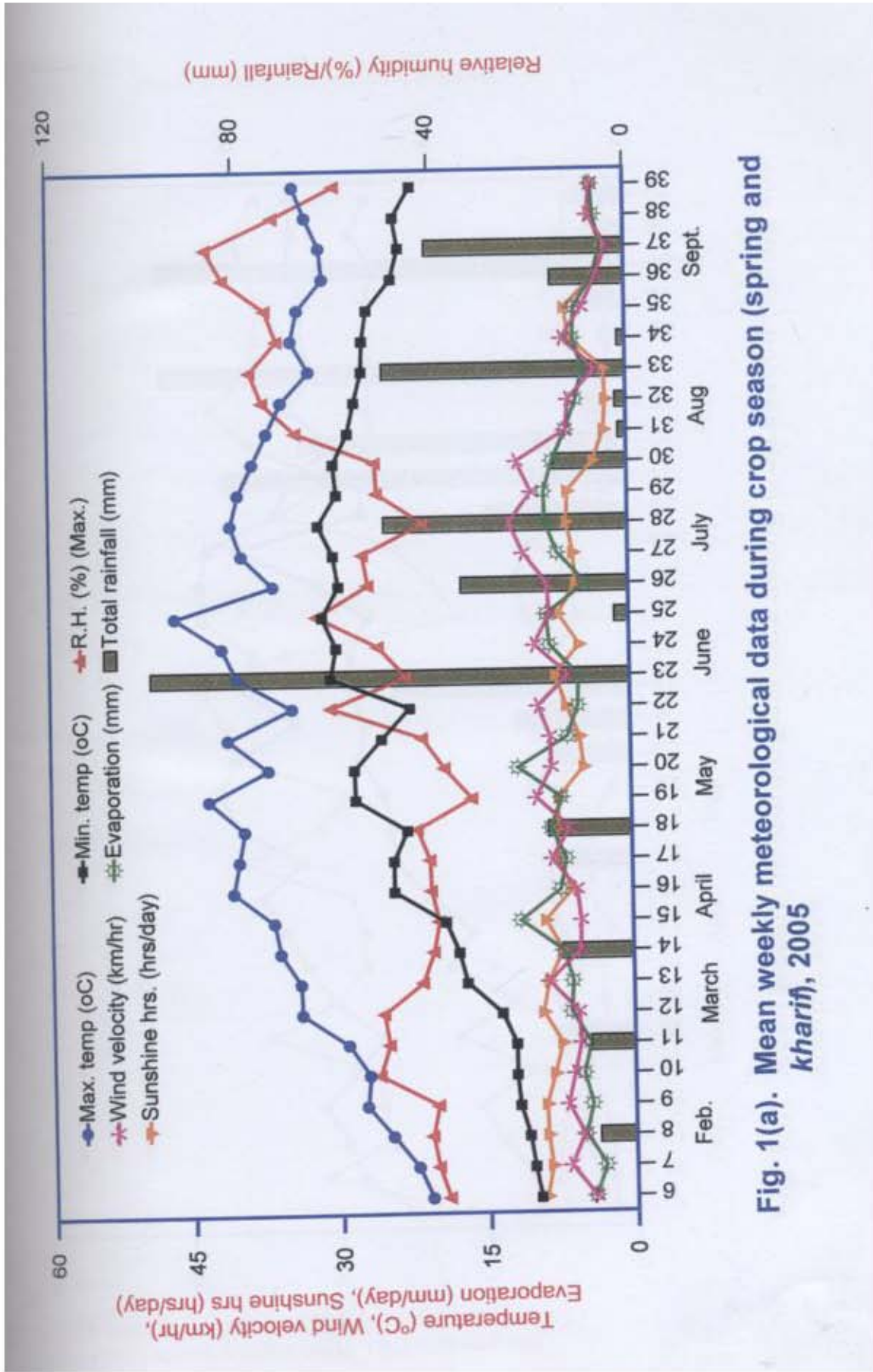
Levels of boron

B_0 = 0 kg/ha

B_1 = 0.75 kg/ha

B_2 = 1.50 kg/ha

FIG. 2. LAYOUT OF PLAN OF FIELD EXPERIMENT



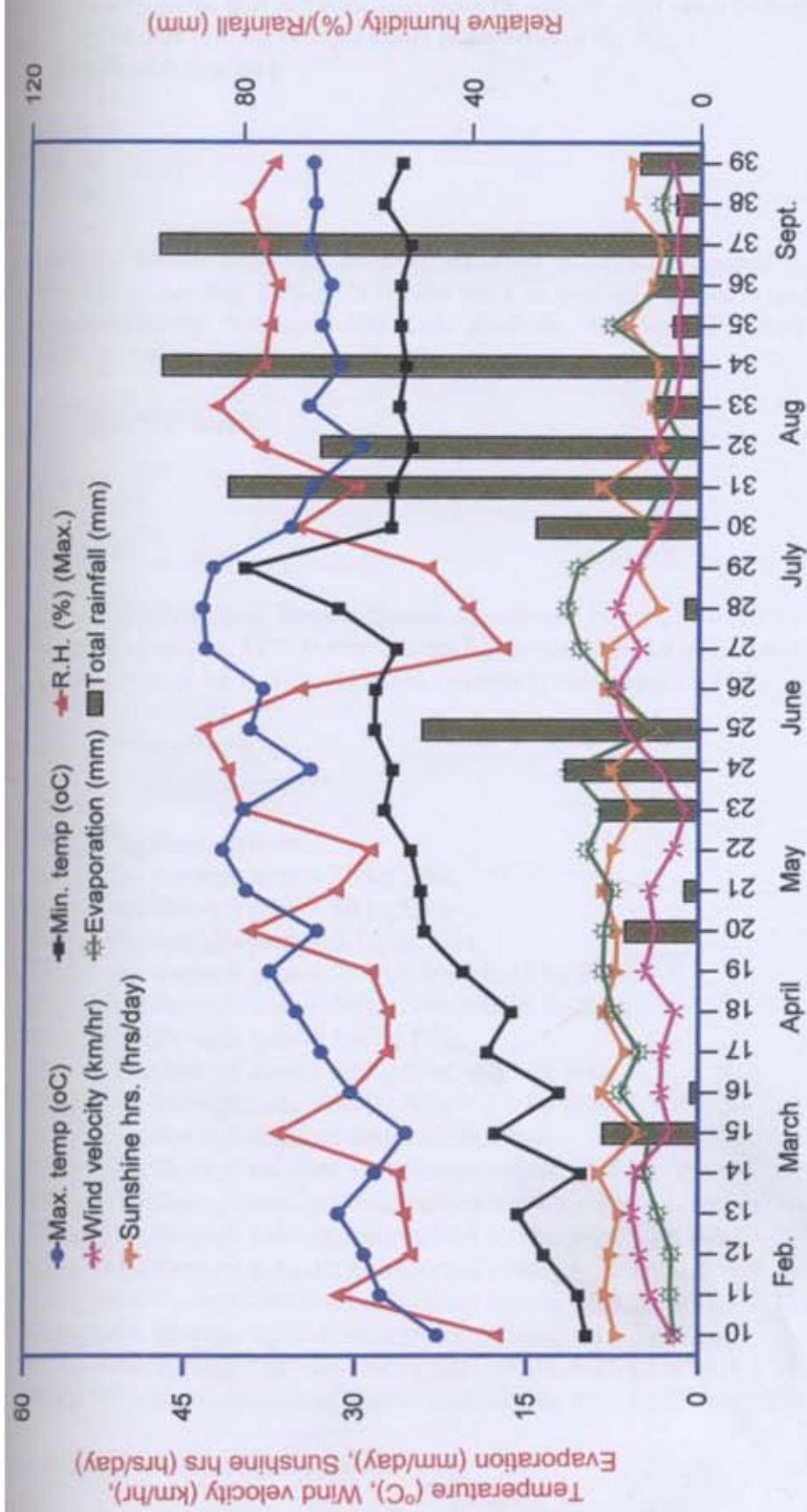


Fig. 1(b). Mean weekly meteorological data during crop season (spring and kharif), 2006

N. The particle size of the material is such that it is completely retained on 1 mm IS sieve and not less than 80% by weight of it shall passed through 4 mm sieve. Per unit kg N from CAN costs around Rs 30).

(B) Levels of S (kg/ha):

- (1) 0
- (2) 25
- (3) 50

Note: S source used was cosavet: Cosavet is brown coloured water dispersible powder containing 80% S. It is also used as contact fungicide and acaricide. It is synthesized by Sulphur Mills Ltd, Andheri, Mumbai. Per unit kg S through cosavet costs approximately Rs 25.

(C) Levels of B (kg/ha)

- (1) 0
- (2) 0.75
- (3) 1.50

Note: Boron source Borax: Borax or sodium borate is a white salt soluble in water. It contains 11% boron. As such it is suitable for soil application and foliar spray. Per unit kg B through borax oximately costs app Rs 313.

Treatment combinations:

- (1) Control
- (2) 80 kg N/ha through urea
- (3) 80 kg N/ha through urea + 25 kg S/ha
- (4) 80 kg N/ha through urea + 50 kg S/ha
- (5) 80 kg N/ha through urea + 0.75 kg B/ha
- (6) 80 kg N/ha through urea + 25 kg S/ha + 0.75 kg B/ha
- (7) 80 kg N/ha through urea + 50 kg S/ha + 0.75 kg B/ha
- (8) 80 kg N/ha through urea + 1.5 kg B/ha
- (9) 80 kg N/ha through urea + 25 kg S/ha + 1.5 kg B/ha
- (10) 80 kg N/ha through urea + 50 kg S/ha + 1.5 kg B/h
- (11) 80 kg N/ha through calcium ammonium nitrate
- (12) 80 kg N/ha through calcium ammonium nitrate + 25 kg S/ha
- (13) 80 kg N/ha through calcium ammonium nitrate + 50 kg S/ha
- (14) 80 kg N/ha through calcium ammonium nitrate + 0.75 kg B/ha
- (15) 80 kg N/ha through calcium ammonium nitrate + 25 kg S/ha + 0.75 kg B/ha
- (16) 80 kg N/ha through calcium ammonium nitrate + 50 kg S/ha + 0.75 kg B/ha
- (17) 80 kg N/ha through calcium ammonium nitrate + 1.5 kg B/ha
- (18) 80 kg N/ha through calcium ammonium nitrate + 25 kg S/ha + 1.5 kg B/ha
- (19) 80 kg N/ha through calcium ammonium nitrate + 50 kg S/ha + 1.5 kg B/ha

Total number of treatment combinations : 18+1=19

Replications: 3

Total number of plots: $19 \times 3 = 57$

3.2.1.3 Plot size

Gross plot size = 6 m x 2.25 m

Net plot size = 5 m x 1.80 m

3.2.1.4 Variety

Sunflower : 'JK Chitra' : It is a hybrid sunflower variety developed by J.K. Seeds Ltd. It is suitable variety for growing in spring season. It matures between 100-110 days. Best sowing time for this hybrid is second fortnight of February. It has large head diameter and bold seeds with yield potential up to 2500 kg/ha.

Mungbean : 'Pusa Vishal': It is variety developed by the Division of Genetics, Indian Agricultural Research Institute, New Delhi in 2000. The name for it is 'Pusa Bold'. It matures in about 70-75 days and is suitable to be grown in North-Western Plain Zone. This variety has gained quick popularity due to its bold seeds which fetch better price in the market. It is equally suitable for cultivation as a summer and *kharif* crop. It is also resistant to yellow mosaic virus.

3.3 Cultural operations

The schedule of the field operations carried out in both the years is presented in Table 4.

3.3.1 Preparatory tillage operations

Land was ploughed using a tractor drawn disc plough. Discing and harrowing were done followed by planking in both the years for sunflower crop. Then the field was laid out for applying treatments. After the harvest of sunflower crop, the land was prepared to sow succeeding mungbean.

3.3.2 Fertilizer application

Basal dose of fertilizers, consisting of half the dose of N and full doses of S and B were applied before sowing of sunflower by drilling through funnel attached behind the country plough in the rows precisely. The rest half of N was supplied at 35 days after sowing (DAS). N was supplied through two different sources i.e. urea and CAN. S was supplied as Cosavet which contains 80% S and boron through borax having 11% B content.

3.3.3 Seed and sowing

Table 4. Calender of cultural operations

Operation	Date of operation	
	2005	2006
Sunflower		
Land preparation and field layout	11-25 Feb.	7-14 Feb.
Fertilizer application	24 Feb.	14 Feb.
Sowing of the crop	25 Feb.	15 Feb.
Thinning and gap filling	2 March	26 Feb.
First irrigation	17 March	10 March
Hand weeding	20 March	14 March
Second irrigation	12 April	1 April
N application	14 April	4 April
Third irrigation	27 April	20 April
Fourth irrigation	16 May	9 May
Harvesting of crop	30 May	22 May
Mungbean		
Land preparation and field layout	10-15 July	17-20 July
Sowing of the crop	16 July	20 July
Hand weeding	30 July	2 Aug.
First irrigation	13 Aug.	19 Aug.
Hand weeding	16 Aug.	22 Aug.
Second irrigation	20 Aug.	25 Aug.
Harvesting (I picking)	18 Sept.	14 Sept.
(II picking)	28 Sept.	24 Sept.

Sunflower seed at the rate of 8 kg/ha was sown in rows at 45 cm distance, keeping 20 cm plant to plant distance/spacing. Seeds were sown at 5 cm depth using dibbling method manually. In case of mungbean, seed at the rate of 15 kg/ha was sown with a distance of 30 cm maintained between row to row and 8 cm plant to plant.

3.3.4 Thinning and gap filling

To have the desired plant population, two weeks after sowing, thinning and gap filling were done so as to maintain the plant to plant distance of 20 cm in sunflower crop.

3.3.5 Weed management

For both sunflower and mungbean, one hand weeding was done at 30-35 DAS to reduce crop-weed competition from weeds.

3.3.6 Water management

In both crop seasons (2005 and 2006), pre-sowing irrigation was given to aid land preparation for sunflower sowing. Thereafter irrigation was given whenever it was required. A total of four irrigations were given during crop season.

For mungbean, monsoon rains rendered water for establishment and growth. Single irrigation was provided in both the years due to long dry spell during the whole mungbean crop growth period.

3.3.7 Harvesting

The crop was harvested only from the net plot area for the study purpose. The harvested heads were then threshed manually and the seeds were collected. The weight of cleaned seeds was recorded as net plot yield. Also dried stover from each plot was harvested and weighed. Both seed and stover yield were expressed as kg/ha.

Mungbean was harvested through picking the pods manually 2 times at 60 and 70-75 DAS in both the crop years.

3.4 Biometric observations

(A) Sunflower

Observations on plant height, leaf area, chlorophyll content and dry matter accumulation were taken on 25 DAS, 50 DAS, 75 DAS and at harvest stages.

Destructive sampling was followed and samples were taken from area outside the net plot area i.e. border area.

3.4.1 Growth attributes

3.4.1.1 Plant height (cm)

The height of five randomly selected and marked plants was measured from ground level to the tip of the plant at 25 DAS, 50 DAS, 75 DAS and at harvest stages. The mean height was expressed in cm.

3.4.1.2 Leaf area index (LAI)

Leaf area (cm²) was measured at 25 DAS, 50 DAS and 75 DAS by the Model 8100 Area Meter (Li-COA). Leaf area index was calculated by formula given by Mckee (1964).

$$\text{LAI} = \frac{\text{Total leaf area per plant (cm}^2\text{)}}{\text{Land area under per plant (cm}^2\text{)}}$$

3.4.1.3 Dry matter accumulation

Every time five plants were uprooted at 25 DAS, 50 DAS, 75 DAS and at harvest. After sun drying these plant samples were dried at $65 \pm 2^\circ\text{C}$ for 24 hours and weight was recorded separately for stem, leaves and root. Dry matter accumulation was expressed as g/plant in the respective plant parts.

3.4.1.4 Crop growth rate (CGR)

It represents dry weight gained by a unit area of crop in a given time. It was calculated by using formula of Watson (1952) and expressed as g/m²/day.

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1 \times A} \times (\text{g/cm}^2/\text{day})$$

Where, A = 1 cm², W₁ and W₂ are the dry weights at times T₁ and T₂, respectively.

3.4.1.5 Relative growth rate

RGR indicates the increase in dry weight in a time interval in relation to the initial weight. The formula to calculate RGR was:

$$\text{Ln } W_2 - \text{Ln } W_1$$

$$\text{RGR} = \frac{W_2 - W_1}{T_2 - T_1} \quad \text{g/g/day}$$

Where, W_1 and W_2 are dry weight at T_1 and T_2 , respectively.

3.4.1.6 Net assimilation rate (NAR)

NAR is a measure of the average rate of net CO_2 exchange per unit area of leaf. It indicates the average photosynthetic efficiency of leaves (Gardner *et al.*, 1985). It is the dry matter accumulation per unit leaf area per unit time. It was calculated using the following formula:

$$\text{NAR} = \frac{(W_2 - W_1) (\ln LA_2 - \ln LA_1)}{(T_2 - T_1)(LA_2 - LA_1)} \quad (\text{g/cm}^2/\text{day})$$

Where W_1 and W_2 are dry weights at time T_1 and T_2 , respectively and LA_2 and LA_1 , are the leaf area values at time T_2 and T_1 , respectively. It is expressed as $\text{g/cm}^2/\text{day}$.

3.4.1.7 Total chlorophyll content

For estimation of total chlorophyll content in the sunflower leaves one gram of sliced fresh leaf was transformed into test tube and 20 ml of extractant medium (consisting of 450 ml of 99% acetone, 450 ml of 99.7% alcohol and 100 ml distilled water) was added to leaf slices and were stored in dark for 24 hours. The suspension was filtered and chlorophyll content was assessed using spectrophotometer at 652 nm wave length. The total chlorophyll content was derived by using formula given by Shivay *et al.* (2002).

$$\text{Chlorophyll content (mg/g fresh weight of leaf)} = 34.5 \times \text{OD}_{652} \times 20 \text{ ml}/1.0 \text{ g}$$

Where, 34.5 is a constant

OD_{652} is optical density reading at 652 nm wave length

1.0 g is weight of sample used of fresh leaf

2. Mungbean

3.4.2 Biometric observations

The biometric observations were recorded at the time of harvest of the crop. From each plot, observations were taken from randomly selected five plants from sampling row which were tagged and labeled with proper notations.

3.4.2.1 Number of branches/plant

All the branches of main and lateral shoots of the five tagged plants were counted at the time of harvest for number of branches/plant.

3.4.2.2 Number of pods/plant

Number of pods was counted at the time of harvest and average number of pods/plant was worked out.

3.4.2.3 Number of grains/pod

Ten pods were threshed carefully and number of grains was counted. The average was worked out to get the number of grains/pod.

3.4.3 Yield attributes

3.4.3.1 Capitulum diameter

The distance between the two diagonally opposite edges of the capitulum was recorded from three randomly selected representative heads from every plot. The average value was expressed in cm.

3.4.3.2 Number of seeds per capitulum

Seeds from the manually threshed sample heads were cleaned and counted using the seed counter (Model Numigral-II, tripette & renaud). The average number of seeds/head was recorded.

3.4.3.3 Seed weight per capitulum

The seeds from three capitulums from a single plot were weighed and their average was taken and then expressed as gram (g) per capitulum.

3.4.3.4 1000-seed weight

Thousand seeds were separated randomly from the sample seed lot collected from each plot. The weight of these 1000-seeds was recorded in gram (g).

3.4.4 Yield

3.4.4.1 Seed yield

The heads harvested from each net plot were threshed manually and seeds were cleaned and weighed. Seed yield was recorded in kg/ha.

3.4.4.2 Stover yield

After separation of head, the stalks of each plot were bundled, tied, sun dried and the total weight per plot was calculated. The stover yield in kg/ha was computed from per plot yield.

3.4.4.3 Total biomass yield

The dry weight of all plant parts were recorded and finally added to get the total biomass at harvest stage. It was expressed in kg/ha.

3.4.4.4 Harvest index

Harvest index was calculated using the following relationship.

$$\text{HI (\%)} = \frac{\text{Economic yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

Hence, economic yield = Seed yield (kg/ha)

Biological yield = Leaf weight + Stem weight + Head weight + Seed yield (kg/ha)

3.4.5 Quality parameters

3.4.5.1 Content and yield of oil

The seed oil content of sunflower was determined using the pulse nuclear magnetic resonance (NMR) technique (Tiwari and Benk, 1980) and was expressed in percentage. The oil yield was calculated using the equation given below:

$$\text{Oil yield (kg/ha)} = \frac{\text{Oil content (\%)} \times \text{Seed yield (kg/ha)}}{100}$$

3.4.5.2 Protein content

Protein content was determined by multiplying the seed N concentration (%) by a coefficient or factor 6.25.

3.4.5.3 Fatty acid analysis

The cold extraction method of Folch *et al.* (1957) was used for extraction of total lipids from sunflower seeds. The fatty acids were analysed in AIMIL-NUCON 5500 Model Gas Liquid Chromatograph (GLC) equipment.

Iodine value, saponification value and acid value of sunflower oil was estimated following the standard methods given by Association of Official Analytical Chemists (AOAC).

3.4.6 Chemical analysis

3.4.6.1 Plant analysis

The plant samples collected for dry matter accumulation estimation were ground into fine powder and used for chemical analysis to find out the concentration of nutrients in different plant parts and the uptake of these nutrients at 25 DAS, 50 DAS, 75 DAS and at harvest were calculated.

3.4.6.2 Nitrogen

The N concentration of plant samples was estimated by micro-kjeldahl method (Prasad *et al.*; 2006). Uptake was obtained by dividing the per cent N concentration by 100 and multiplying with the corresponding dry matter yield of the plant parts and expressed as mg/plant and total uptake as kg/ha.

3.4.6.3 Phosphorus

The estimation of P concentration in plant samples was done using colorimetry as described by Prasad *et al.* (2006). Uptake of P was expressed per plant as mg/plant and total P uptake in kg/ha.

3.4.6.4 Potassium

The K concentration in plant samples was determined using flame photometry (Prasad *et al.*, 2006) and uptake was calculated both in mg/plant and kg/ha.

3.4.6.5 Sulphur

Total S concentration in plant samples were measured by Barium sulphate turbidimetry method (Prasad *et al.*, 2006). Per plant uptake was expressed in mg/plant and totals uptake in kg/ha.

3.4.5.6 Boron

Total B concentration in different plant parts at different stages was estimated with determination by azomethine-H method (Prasad *et al.*, 2006). The concentration was given in mg/kg dry matter of plant and total uptake in g/ha.

3.5 Soil analysis

Soil samples were taken from three depths i.e. 0-20, 20-40, 40-60 cm before the start of the experiment and after the harvest of both sunflower crops in 2005 and 2006. For succeeding mungbean crop the sample from surface soil (0-20 cm depth) were analysed. Pre-experimental composite sample was analysed for mechanical and

physical properties and also for available nutrients. All the post harvest samples were shade dried and sieved through 2 mm sieve and used for estimation of available N, P, K, S and B.

3.5.1 Available N

This was estimated by alkaline KMnO_4 method as suggested by Subbiah and Asija (1956) and expressed as kg/ha.

3.5.2 Available P

Available P was estimated following method proposed by Olsen *et al.* (1954) and expressed in kg/ha.

3.5.3 Available K

Available K was determined using neutral normal ammonium acetate (1 N NH_4OAC) method and flame photometry as described by Stanford and English (1949) and expressed in kg/ha.

3.5.4 Available S

Estimation of available soil S content was done by turbidimetric method by using colorimeter (Williams and Steinberg, 1959) and expressed in kg/ha.

3.5.5 Available B

Available B was estimated by hot water treatment (Singh *et al.*, 1999) and was expressed in g/ha.

3.6 Economic analysis

Total expenditure as well as total gross and net monetary returns for sunflower were worked out using existing rates of prices of inputs and produce during the cropping periods. The response to S and B was studied by fitting different response equations for seed yield. The quadratic response equation was found to be best fitted to define the relationship between x & Y as shown below:

$$Y = a + bx + cx^2$$

Where, Y = seed yield (kg/ha)

x = level of S and B (kg/ha)

a, b & c = constants of quadratic response equations/function.

(A) Economic Optimum Dose:

The economic optimum dose (EOD) of S & B (kg/ha) was computed using the following equation:

$$X_{\text{opt}} (\text{EOD}) = \frac{[(q/p)-b]}{2c}$$

whereas b & c are two constants of quadratic response function; q is the per unit cost of S or B and p is the price of seed yield.

While maximum yield dose can be calculated as:

$$X_{\text{max}} = \frac{-b}{2c}$$

(B) The yield at EOD of S & B was computed by using quadratic equation

$$Y = a + bx + cx^2$$

Whereas, Y = seed yield (kg/ha) at EOD; x = EOD of S or B (kg/ha); a, b & c = constants of quadratic response.

(C) The response to economic optimum dose (REOD) of S or B was computed by using the equation:

$$\text{REOD} = Y_{\text{opt}} - Y_{\text{control}}$$

Where, Y_{opt} = Yield computed at EOD; $Y_{\text{cont.}}$ = Yield computed at control

(D) Response in kg/kg input for S and B

$$R = \frac{\text{Response at optimum dose (kg/ha)}}{\text{Optimum dose (kg S or B/ha)}}$$

(E) Profit = Value of the produce (kg/ha) – Cost of S or B/ha
 = [Response at optimum dose x Selling price of seed (Rs/kg)
 - [Cost of 1 kg S or B x optimum dose (kg S or B)]

(F) Return in Rs/Re on S and B

$$R = \frac{\text{Profit/ha}}{\text{Optimum dose of S x cost of S or B/kg}}$$

3.7 Statistical analysis

The data collected from the field and laboratory work were computed and properly tabulated. Then these were subjected to standard analysis using analysis of variance technique as proposed by Gomez and Gomez (1983). ' F ' test was carried out for significance of comparison and critical difference (LSD) at 5% level of probability was worked out wherever F values were significant. The LSD values were used to draw conclusions from treatment comparisons.



A general view of sunflower crop grown during field experimentation

EXPERIMENTAL RESULTS

The results of the field experiments conducted during spring and rainy seasons of 2005 and 2006 on sunflower and mungbean, as well as data from the laboratory analysis carried out, were statistically analysed and are presented in this chapter under different sections.

4.1 Effect of N sources, S and B levels on sunflower

4.1.1 Growth characters

4.1.1.1 Plant height

The data on plant height were recorded at 25, 50, 75 DAS (days after sowing) and at harvest stages during both the crop seasons and are presented in Table 5.

The rate of increase in plant height was very high between 25 and 50 DAS in both the years. Plant height also increased up to harvest stage but the rate of increase diminished with the increase in stage of crop. The plant height was slightly lower at different growth stages in the second year of the experimentation.

Data pertaining to plant height in the table 5 revealed that N sources had no significant effect on plant height at any of the stages except at 50 DAS where CAN performed a little better than urea.

A significant increase in plant height was recorded by application of S at all stages except 25 DAS during both the years of the study. A sharp increase was noticed when level of S was increased from 0 to 25 kg/ha but the subsequent dose of 50 kg S/ha could not bring much change at later stages of crop growth.

Application of B produced taller plants in both the years at all the stages of crop growth. The much gain in plant height was noticed at the application of first dose of B @ 0.75 kg/ha and proved to be more effective than the higher dose of 1.5 kg B/ha. The similar trend was followed in both the years of the study. Whereas, all the

Treatments	Plant height (cm)									
	2005					2006				
	25 DAS	50 DAS	75 DAS	At harvest	25 DAS	50 DAS	75 DAS	At harvest	75 DAS	At harvest
Nitrogen sources										
PU	10.6	101.1	159.2	173.8	10.0	96.6	143.9	159.6		
CAN	10.6	110.6	156.4	176.8	10.2	103.5	149.9	165.6		
SEM +	0.18	1.52	2.03	2.64	0.12	2.35	2.52	2.52		
LSD (P=0.05)	NS	4.21	NS	NS	NS	6.50	NS	NS		
Sulphur levels (kg/ha)										
0	10.3	94.5	151.7	168.6	10.1	99.9	141.2	151.2		
25	10.4	101.5	160.0	174.7	10.3	101.6	146.3	164.3		
50	10.9	121.6	161.8	182.7	10.4	107.7	153.3	172.5		
SEM +	0.22	1.86	2.23	3.24	0.20	2.60	2.79	2.81		
LSD (P=0.05)	NS	5.16	6.17	8.99	NS	4.70	7.78	7.80		
Boron levels (kg/ha)										
0	10.3	102.2	151.3	166.7	10.1	95.5	136.4	151.3		
0.75	10.5	104.5	157.6	174.7	10.4	99.5	143.4	161.5		
1.50	11.0	110.8	164.5	184.5	10.4	105.5	151.9	174.9		
SEM +	0.22	1.86	2.23	3.24	0.20	2.60	2.79	2.81		
LSD (P=0.05)	0.62	5.16	6.17	8.99	NS	4.70	7.78	7.80		
Absolute control	9.7	82.0	137.0	159.0	9.5	78.1	128.6	145.6		
Rest	10.6	105.8	157.8	175.3	10.3	100.1	146.9	162.6		
SED +	0.32	4.56	3.23	7.94	0.49	4.24	4.20	6.82		
LSD (P=0.05)	0.64	9.21	6.52	16.03	0.98	8.56	8.48	13.77		

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing.

treatments were significantly superior than control during both the years of experimentation.

4.1.1.2 Dry matter accumulation

The results pertaining to dry matter accumulation of sunflower in different plant parts and total dry matter accumulation are presented in Table 6-9 and Fig. 3. At 25 DAS, leaf accumulated the highest dry matter followed by stem and root in both the years of the study. At 50 DAS, stem became the major accumulative portion. A drastic increase in individual dry matter of plant parts, separately and total dry matter accumulation was observed during 50 and 75 DAS, but numerically the dry matter was higher in the first year. At harvest stage also, stem was the major contributor to the total dry matter accumulation per plant. The dry weight of leaves declined during the last stage, while the shoot and root dry weight was still at increasing trend. However, the increase was very meagre.

The effect of N sources on dry matter accumulation in different parts of sunflower plant recorded at 25, 50, 75 DAS and at harvest was found to be non-significant in most of the cases during both the years of the study.

S application had a profound effect on the dry matter accumulation by sunflower plant in all its parts including stem, leaves and roots at all growth stages. However, the dry matter enhancement was lower during 25 DAS, the increase was dramatically higher at 50 and 75 DAS. At harvest stage, the increase in stem and shoot was lower and dry weight of leaf declined whereas head accumulated quite an enough biomass. Similar trend was followed in both the years of the study.

Dry matter accumulation was significantly influenced by the application of B. B application @ 0.75 kg/ha registered higher rate of dry matter accumulation at all the crop growth stages but the response was less comparatively at 1.5 kg B/ha. The partitioning of dry matter accumulation was higher towards leaves at 25 DAS and at 50 and 75 DAS, stem occupied the premier place followed by root. At harvest stage, without further enhancement in dry weight of vegetative parts, head increased its volume. The results were confirmed by the similar pattern of dry matter partitioning in the second year of the study.

Treatments	Dry matter accumulation (g/plant)											
	2005					2006						
	Leaf	Stem	Root	Total	Leaf	Stem	Root	Total	Leaf	Stem	Root	Total
Nitrogen sources												
PU	1.34	0.40	0.20	1.95	1.29	0.31	0.17	1.77				
CAN	1.33	0.42	0.21	1.96	1.31	0.33	0.21	1.85				
SEM ±	0.02	0.07	0.02	0.03	0.02	0.04	0.02	0.03				
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS				
Sulphur levels (kg/ha)												
0	1.33	0.36	0.15	1.87	1.25	0.26	0.14	1.65				
25	1.34	0.42	0.22	2.01	1.31	0.35	0.22	1.88				
50	1.34	0.45	0.24	2.06	1.35	0.37	0.23	1.95				
SEM ±	0.02	0.008	0.03	0.04	0.02	0.05	0.03	0.03				
LSD (P=0.05)	NS	0.023	0.09	0.11	0.06	NS	0.09	0.10				
Boron levels (kg/ha)												
0	1.23	0.37	0.20	1.80	1.18	0.29	0.18	1.65				
0.75	1.37	0.41	0.20	1.98	1.33	0.32	0.19	1.84				
1.50	1.41	0.45	0.22	2.08	1.40	0.37	0.21	1.98				
SEM ±	0.02	0.008	0.03	0.04	0.02	0.05	0.03	0.03				
LSD (P=0.05)	0.07	0.023	NS	0.11	0.06	NS	NS	0.10				
Absolute control												
Rest	0.82	0.28	0.12	1.22	0.73	0.25	0.1	1.11				
SED +	1.34	0.41	0.20	1.95	1.30	0.32	0.19	1.81				
SEM ±	0.04	0.05	0.04	0.010	0.05	0.06	0.04	0.04				
LSD (P=0.05)	0.08	0.11	0.08	0.020	0.10	0.18	0.08	0.08				

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Table 7. Effect of nitrogen sources, sulphur and boron levels on dry matter accumulation at 50 DAS of sunflower

Treatments	Dry matter accumulation (g/plant)									
	2005					2006				
	Leaf	Stem	Root	Total		Leaf	Stem	Root	Total	
Nitrogen sources										
PU	9.02	16.18	6.25	31.45		8.68	14.02	6.38	29.08	
CAN	8.97	15.31	6.55	30.83		8.78	15.09	6.48	30.35	
SEM ±	0.15	0.28	0.11	0.49		0.13	0.22	0.01	0.04	
LSD (P=0.05)	NS	0.73	0.30	NS		NS	NS	NS	NS	
Sulphur levels (kg/ha)										
0	8.78	13.53	6.22	28.53		8.17	12.15	6.15	26.47	
25	8.93	15.03	6.41	30.37		8.43	14.25	6.55	29.23	
50	9.26	18.67	6.56	34.49		9.59	17.27	6.61	33.47	
SEM ±	0.18	0.34	0.13	0.60		0.17	0.28	0.14	0.78	
LSD (P=0.05)	NS	0.95	NS	1.67		0.47	0.77	0.37	2.15	
Boron levels (kg/ha)										
0	8.55	14.02	6.05	28.62		8.11	12.39	5.97	26.60	
0.75	9.06	16.32	6.39	31.77		8.85	14.09	6.36	29.43	
1.50	9.36	16.88	6.76	33.00		9.25	17.17	6.57	33.12	
SEM ±	0.18	0.34	0.13	0.60		0.17	0.28	0.14	0.78	
LSD (P=0.05)	0.50	0.95	0.36	1.67		0.47	0.77	0.37	2.15	
Absolute control	7.91	9.10	5.11	22.12		7.08	8.68	4.17	19.93	
Rest	8.99	15.74	6.40	31.13		8.73	14.55	6.43	29.71	
SED ±	0.21	0.74	0.15	2.32		0.32	0.65	0.28	2.47	
LSD (P=0.05)	0.42	1.49	0.30	4.68		0.64	1.31	0.56	4.98	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Table 8. Effect of nitrogen sources, sulphur and boron levels on dry matter accumulation at 75 DAS of sunflower

Treatments	Dry matter accumulation (g/plant)									
	2005					2006				
	Leaf	Stem	Root	Total		Leaf	Stem	Root	Total	
Nitrogen sources										
PU	31.84	40.29	14.56	86.70		29.47	36.92	13.07	80.15	
CAN	32.60	40.27	14.63	87.51		30.84	38.52	14.45	83.12	
SEm +	0.50	0.57	0.21	1.35		0.45	0.50	0.20	0.11	
LSD (P=0.05)	NS	NS	NS	NS		1.25	NS	NS	NS	
Sulphur levels (kg/ha)										
0	31.08	37.58	14.51	83.17		28.21	35.25	12.33	75.79	
25	32.63	40.55	14.41	87.59		30.15	37.71	13.94	81.80	
50	32.93	42.72	14.85	90.50		32.10	40.22	15.03	87.35	
SEm +	0.62	0.70	0.26	1.66		0.70	0.69	0.21	1.28	
LSD (P=0.05)	1.71	1.95	NS	4.59		1.69	1.85	0.70	3.54	
Boron levels (kg/ha)										
0	28.71	37.48	13.75	79.95		27.70	35.61	12.25	75.56	
0.75	32.71	40.42	14.56	87.70		29.43	37.24	13.78	80.45	
1.50	35.23	42.94	15.48	93.66		33.23	40.31	15.25	88.79	
SEm +	0.62	0.70	0.26	1.66		0.70	0.69	0.21	1.28	
LSD (P=0.05)	1.71	1.95	0.71	4.59		1.69	1.85	0.70	3.54	
Absolute control	22.24	30.74	12.34	65.32		22.24	28.65	11.71	62.60	
Rest	32.21	40.28	14.59	87.09		30.15	37.72	13.76	81.63	
SEd +	2.40	3.14	0.44	1.74		2.41	2.40	0.51	2.65	
LSD (P=0.05)	4.84	6.34	0.88	3.51		4.86	4.84	1.03	5.35	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	Dry matter accumulation (g/plant)									
	2005					2006				
	Leaf	Stem	Root	Capitulum	Total	Leaf	Stem	Root	Capitulum	Total
Nitrogen sources										
PU	26.16	49.01	15.61	17.97	109.09	24.18	46.95	14.77	16.67	102.56
CAN	24.20	49.30	15.34	19.36	107.84	24.20	48.06	15.74	18.67	106.66
SEM +	0.40	0.81	0.23	0.28	1.63	0.32	0.28	0.21	0.25	1.49
LSD (P=0.05)	1.10	NS	NS	0.78	NS	NS	0.77	NS	0.80	NS
Sulphur levels (kg/ha)										
0	23.03	48.34	14.93	17.97	104.25	22.15	43.40	14.21	16.25	96.01
25	25.87	48.05	15.39	18.21	107.50	24.21	47.78	15.35	17.75	105.09
50	26.65	51.08	16.10	19.82	113.63	26.22	51.32	16.20	19.01	112.75
SEM +	0.49	1.00	0.28	0.34	1.99	0.41	0.75	0.27	0.28	2.44
LSD (P=0.05)	1.35	2.76	0.77	0.96	5.53	1.12	2.07	0.60	0.77	6.75
Boron levels (kg/ha)										
0	23.39	43.57	14.81	17.48	99.84	22.60	43.05	13.94	16.24	95.81
0.75	24.93	49.94	15.47	18.40	109.18	23.70	47.21	14.91	17.41	103.21
1.50	27.22	53.95	16.14	20.10	116.36	26.30	52.24	16.92	19.38	114.82
SEM +	0.49	1.00	0.28	0.34	1.99	0.41	0.75	0.27	0.28	2.44
LSD (P=0.05)	1.35	2.76	0.77	0.96	5.53	1.12	2.07	0.60	0.77	6.75
Absolute control	15.10	43.57	13.70	15.21	87.58	14.55	41.35	12.22	15.01	83.13
Rest	25.18	49.15	15.47	18.66	108.46	24.19	47.50	15.25	17.67	104.61
SED +	1.50	2.42	0.50	0.76	2.52	1.32	0.85	0.40	0.65	2.79
LSD (P=0.05)	3.03	4.88	1.01	1.53	5.09	2.66	1.71	0.80	1.31	5.63

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

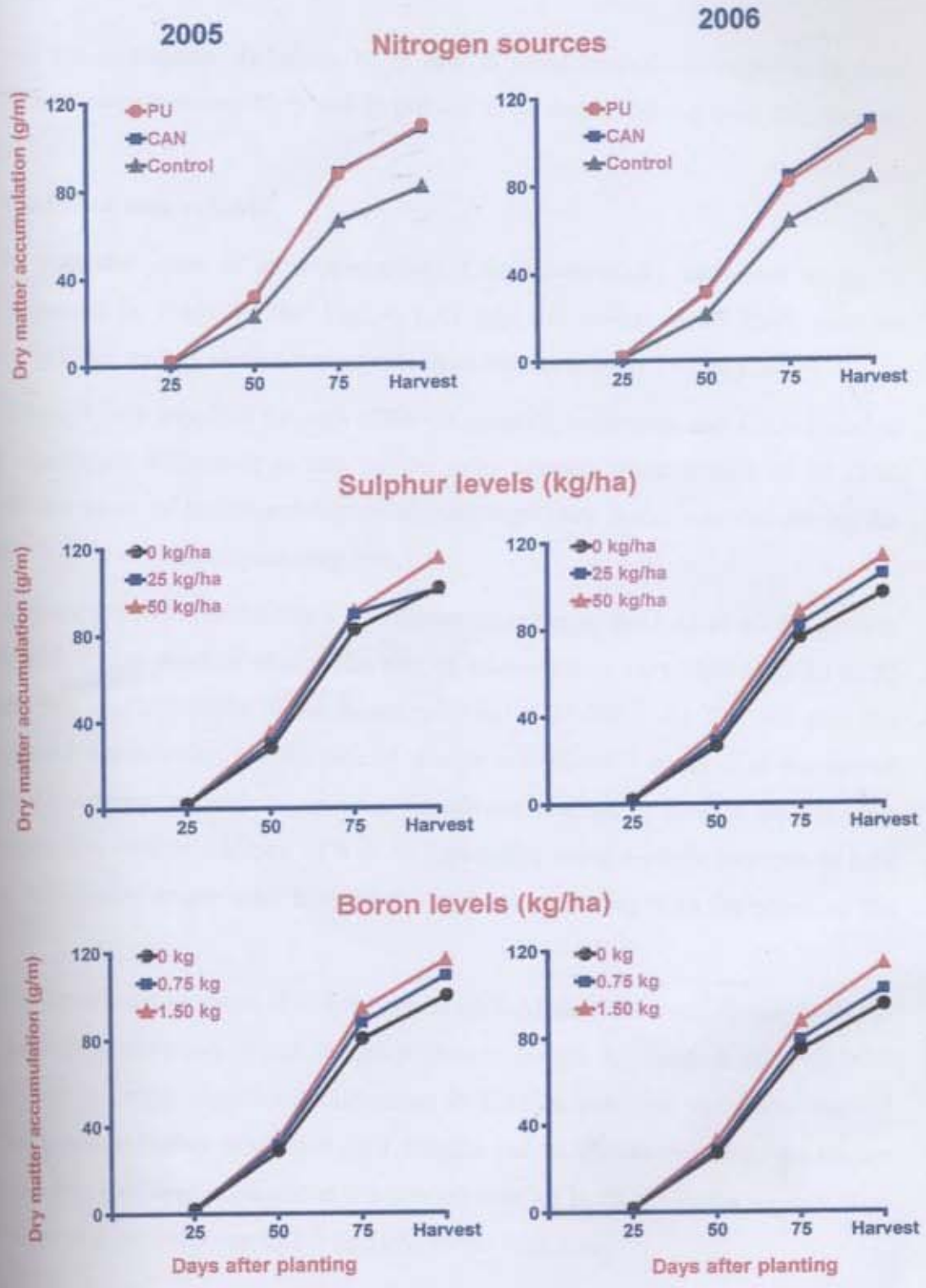


Fig. 3. Dry matter accumulation per plant in sunflower at different stages of crop growth as influenced by nitrogen sources, sulphur and boron levels

All the treatments including N, S and B were statistically significant over control. Treatments receiving N, S and B proved to be better during both the years of the study.

4.1.1.3 Leaf area index (LAI)

In both the years of experimentation, LAI substantially increased up to 75 DAS as indicated in Table 10 and Fig. 4. LAI was the lowest at 25 DAS, with an increase at 50 DAS and an abrupt change was seen between 50 to 75 DAS.

When N was supplied through different sources, both urea and CAN failed to give any significant difference at any of the crop growth stage except at 25 DAS during both the years of the experimentation. Although urea stood superior during the second year but the difference was very less.

Application of S resulted in a significant increase in the LAI at all the growth stages during both the years of study. The rate of increase was very high from 25 to 50 DAS which was nearly 7 times of the figure recorded at 25 DAS. At 75 DAS also, the figure increased numerically, but the rate of change was about 3 times. S at the rate of 25 kg/ha was superior enough to cause a significant change in LAI at all the crop growth stages. The further addition of S at 50 kg/ha also bring a slight increase in LAI but it was statistically at par with S applied @ 25 kg/ha during both the years of the study.

The significant increase of B application on LAI was observed during both the years of the experimentation. At all the crop growth stages, application of B @ 0.75 kg/ha was able to cause significant difference in LAI in the first year. The rate of increase was equal at higher dose of B @ 1.5 kg/ha but in the second year, the higher rate of increase in LAI was observed at the second dose of B @ 1.5 kg/ha as well. The better response of B was seen up to 1.5 kg B/ha in the first year.

The application of various treatments, maintained a clear superiority with regard to LAI over control during both the years of the study. Absolute control resulted in minimum LAI and did not of match to any of the treatment at any crop growth stage of sunflower.

Treatments	Leaf area index (LAI)							
	2005				2006			
	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS
Nitrogen sources								
PU	0.26	1.88	4.65	0.24	1.71	4.36		
CAN	0.25	1.84	4.66	0.22	1.75	4.19		
SEM +	0.003	0.02	0.07	0.001	0.03	0.07		
LSD (P=0.05)	0.009	NS	NS	0.003	NS	NS		
Sulphur levels (kg/ha)								
0	0.24	1.71	4.42	0.21	1.62	4.07		
25	0.26	1.94	4.73	0.24	1.73	4.28		
50	0.27	1.92	4.80	0.26	1.84	4.47		
SEM +	0.004	0.03	0.08	0.002	0.04	0.08		
LSD (P=0.05)	0.012	0.08	0.22	0.006	0.13	0.22		
Boron levels (kg/ha)								
0	0.24	1.72	4.33	0.21	1.61	3.91		
0.75	0.26	1.85	4.71	0.23	1.70	4.22		
1.50	0.28	1.94	4.92	0.26	1.89	4.70		
SEM +	0.004	0.03	0.08	0.002	0.04	0.08		
LSD (P=0.05)	0.012	0.08	0.22	0.006	0.13	0.22		
Absolute control								
Rest	0.17	1.38	3.36	0.16	1.27	3.27		
SEM +	0.26	1.85	4.65	0.23	1.73	4.27		
LSD (P=0.05)	0.01	0.06	0.09	0.003	0.07	0.09		
LSD (P=0.05)	0.02	0.12	0.18	0.010	0.14	0.18		

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

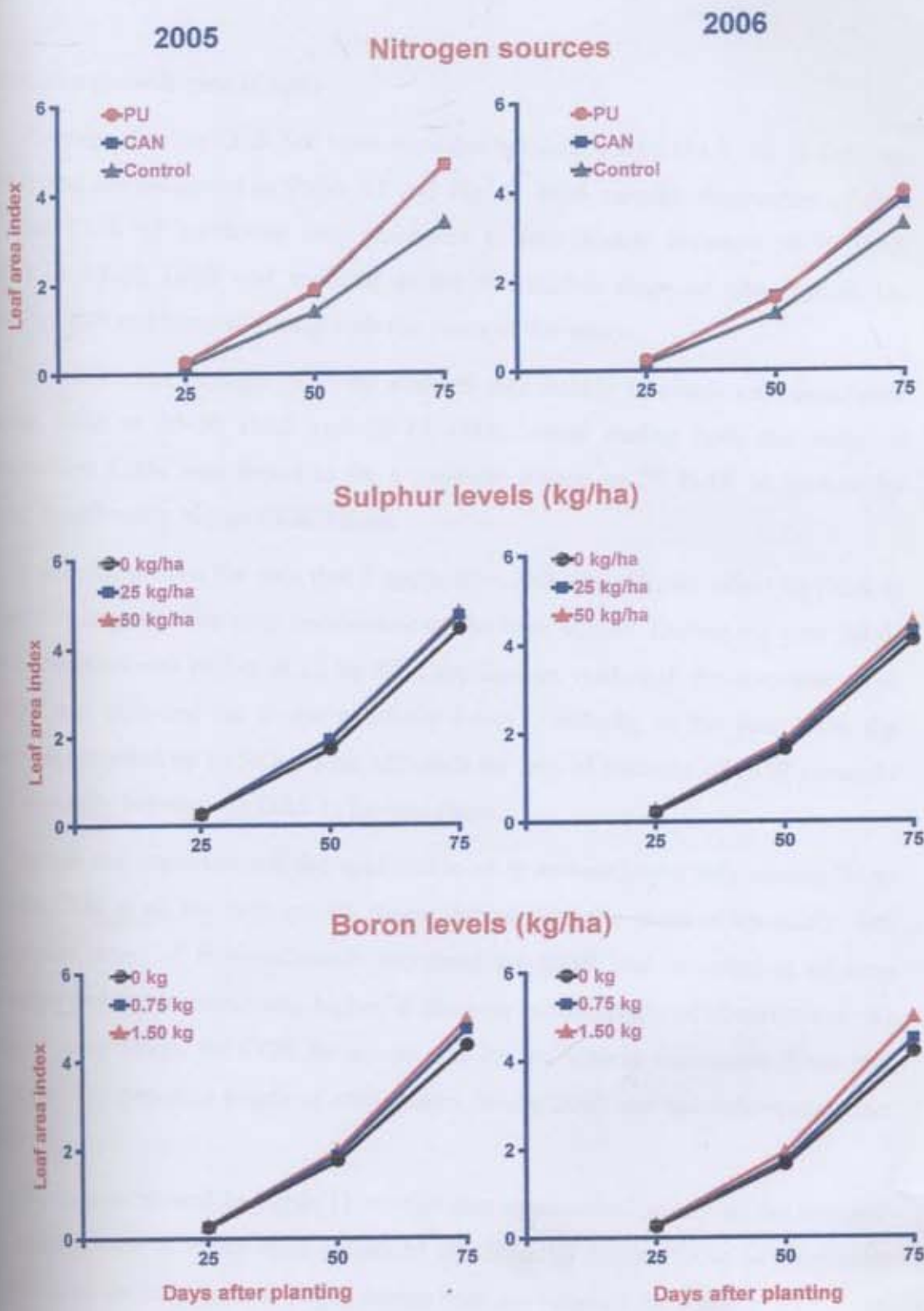


Fig. 4. Leaf area index of sunflower at different stages of crop growth as influenced by nitrogen sources, sulphur and boron levels

4.1.1.4 Crop growth rate (CGR)

Average data on CGR has been recorded between 25-50 DAS, 50-75 DAS up to harvest and are presented in Table 11 and Fig. 5. With careful observation of data reveals that CGR of sunflower crop increased to just double between 50-75 DAS compared to 25-50 DAS and reduced at the successive stage of observation i.e. between 75 DAS and harvest during both the years of the study.

N application through different sources was unable to cause any significant impact on CGR at 25-50 DAS and 50-75 DAS, while during both the years of experimentation CAN was found to be a superior source at 75 DAS to harvest by producing significantly higher CGR values.

It is evident from the data that S application had a significant effect on CGR at all the growth stages of the crop irrespective of the base values. During the year 2005, the rate of increase was higher at 25 kg S/ha application. Although the response up to 50 kg S/ha was recorded but it was relatively lower, similarly, in the year 2006, the response was recorded up to 50 kg S/ha, although the rate of increase of CGR certainly declined, specially between 75 DAS to harvest stage.

As per the expectations, the application of B to sunflower was successful to enhance the CGR at all the crop growth stages during both the years of the study. The two successive doses of B significantly increased the CGR and recorded at all crop growth stages but the increase was higher at the two initial stages of observations. At last stage of observation, the CGR increment was lower, both at successive doses and when compared to previous stages of crop grown during 2005 and the subsequent year as well.

The data presented in Table 11 reveals that application of any of the element through either source at either dose produced significantly higher CGR of sunflower than control at all the crop growth stages during both the years of the study.

4.1.1.5 Relative growth rate (RGR)

The data pertaining to RGR at 3 stages between 25-50 DAS, 50-75 DAS and 75 DAS-to harvest have been recorded for both 2005 and 2006 and are given in Table

Treatments	CGR (g/cm ² /day)						
	2005			2006			
	25-50 DAS	50-75 DAS	75 DAS-harvest	25-50 DAS	50-75 DAS	75 DAS-harvest	
Nitrogen sources							
PU	1.17	2.21	0.93	1.08	2.05	0.91	
CAN	1.15	2.26	0.79	1.11	2.14	0.95	
SEM ±	0.02	0.07	0.01	0.02	0.04	0.01	
LSD (P=0.05)	NS	NS	0.03	NS	NS	0.03	
Sulphur levels (kg/ha)							
0	1.06	2.13	0.82	0.98	1.99	0.82	
25	1.13	2.22	0.79	1.07	2.12	0.93	
50	1.29	2.35	0.97	1.24	2.17	1.03	
SEM ±	0.02	0.08	0.02	0.05	0.03	0.04	
LSD (P=0.05)	0.06	0.15	0.05	0.14	0.09	0.13	
Boron levels (kg/ha)							
0	1.06	2.06	0.78	0.97	1.96	0.82	
0.75	1.17	2.25	0.85	1.08	1.98	0.92	
1.50	1.26	2.39	0.95	1.22	2.30	1.06	
SEM ±	0.02	0.08	0.02	0.05	0.03	0.04	
LSD (P=0.05)	0.06	0.15	0.05	0.14	0.09	0.13	
Absolute control	0.83	1.72	0.61	0.79	1.63	0.58	
Rest	1.16	2.23	0.86	1.09	2.09	0.93	
SED ±	0.04	0.09	0.04	0.06	0.04	0.05	
LSD (P=0.05)	0.08	0.18	0.08	0.12	0.08	0.10	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

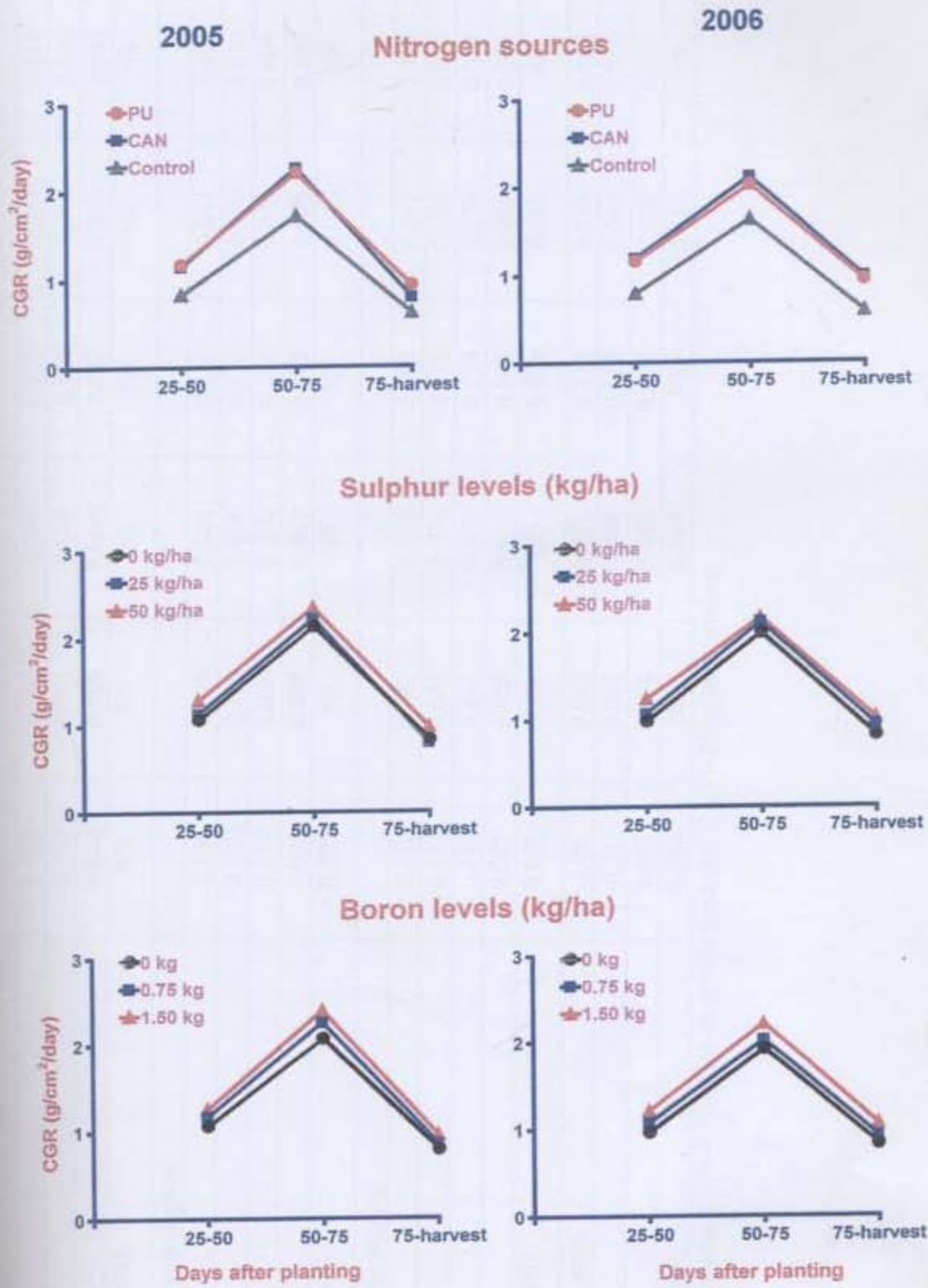


Fig. 5. Crop growth rate of sunflower at different stages of crop growth as influenced by nitrogen sources, sulphur and boron levels

Treatments	RGR (g/g/day)					
	2005			2006		
	25-50 DAS	50-75 DAS	75 DAS-harvest	25-50 DAS	50-75 DAS	75 DAS-harvest
Nitrogen sources						
PU	0.111	0.041	0.009	0.112	0.051	0.010
CAN	0.110	0.041	0.008	0.113	0.048	0.010
SEM +	0.001	0.006	0.0001	0.002	0.004	0.002
LSD (P=0.05)	NS	NS	NS	NS	NS	NS
Sulphur levels (kg/ha)						
0	0.108	0.038	0.008	0.111	0.041	0.009
25	0.109	0.039	0.008	0.112	0.050	0.010
50	0.114	0.049	0.010	0.115	0.056	0.009
SEM +	0.002	0.008	0.002	0.002	0.005	0.001
LSD (P=0.05)	0.005	NS	NS	NS	0.013	NS
Boron levels (kg/ha)						
0	0.110	0.041	0.008	0.105	0.041	0.009
0.75	0.111	0.041	0.008	0.113	0.048	0.010
1.50	0.111	0.041	0.009	0.119	0.059	0.010
SEM +	0.002	0.008	0.002	0.002	0.005	0.001
LSD (P=0.05)	0.005	NS	NS	0.006	0.013	NS
Absolute control	0.08	0.043	0.001	0.110	0.010	0.008
Rest	0.11	0.041	0.008	0.112	0.049	0.010
SED +	0.002	0.008	0.002	0.005	0.006	0.003
LSD (P=0.05)	0.004	NS	0.004	NS	0.012	NS

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

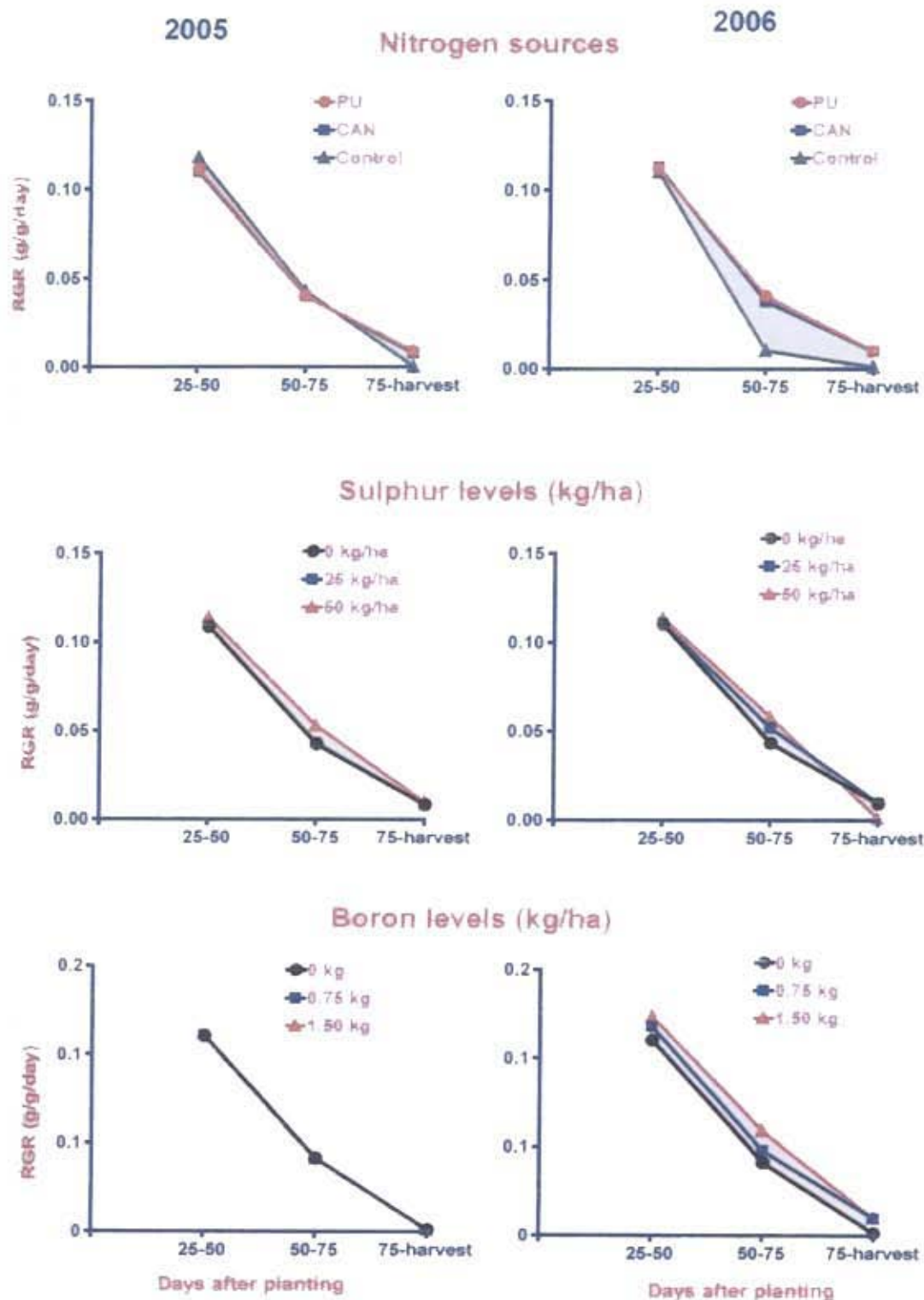


Fig. 6. Relative growth rate of sunflower at different stages of crop growth as influenced by nitrogen sources, sulphur and boron levels

12 and Fig. 6. RGR showed a declining trend from the first crop growth stage till the harvest stage where the decline was more sharper about 70-75% between 50-75 DAS and 75 DAS to harvest could observe only 6-% decrement.

Although, N sources could not make any difference, the application of S, of course, produced significantly better RGR of sunflower during both the years of observations but interestingly, the response at 50 kg S/ha was at par with 25 kg S/ha between 25-50 DAS in 2005. During the same year, between 50-75 DAS, both S doses were able to cause a significant effect. To our surprise, there was no significant increase in RGR between 75 DAS and at harvest. A similar trend was followed in the following year i.e. 2006.

The response of B was more or less similar to S with regards to RGR of sunflower. During both the years of the study, the higher dose of B i.e. 1.5 kg/ha was statistically at par with 0.75 kg B/ha in finalizing RGR at 25-50 DAS. At 50-75 DAS, B was able to cause a significant effect on RGR but again at 75 DAS-at harvest, the effect was diluted and almost similar RGR was produced irrespective of any dose of B. Confirming the results, similar pattern was noticed during the second year of crop raising also.

Again describing the importance of nutrient management, the results were found significantly superior in treatments with N, S or B when comparison to control was done. The RGR in control plots could not stand behind the nutrient applied plots.

4.1.1.6 Net assimilation rate (NAR)

Data recorded on NAR at 3 stages between 25-50 DAS, 50-75 DAS and 75 DAS to harvest stage have been shown in Table 13 and Fig. 7. The highest NAR was recorded during 25-50 DAS, followed by 50-75 DAS and the lowest during 75 DAS to harvest in both the years of the study indicating higher assimilation and growth during earlier phases.

Like previous informations, N sources could not make much difference in NAR of sunflower during any of the year of the experimentation. Although the values of NAR were little higher with CAN but were statistically at par with urea. During 2005, S application proved superior both numerically and statistically at 25-50 DAS. At the advanced stage the difference due to S doses became less. Whereas in the year

Treatments	NAR (g/cm ² /day)					
	2005			2006		
	25-50 DAS	50-75 DAS	75 DAS-harvest	25-50 DAS	50-75 DAS	75 DAS-harvest
Nitrogen sources						
PU	1.57	0.79	0.31	1.61	0.81	0.34
CAN	1.60	0.82	0.36	1.52	0.83	0.34
SEM +	0.02	0.02	0.04	0.03	0.01	0.01
LSD (P=0.05)	NS	NS	NS	NS	NS	NS
Sulphur levels (kg/ha)						
0	1.53	0.78	0.31	1.49	0.78	0.31
25	1.55	0.80	0.32	1.57	0.83	0.35
50	1.68	0.84	0.38	1.64	0.87	0.38
SEM +	0.02	0.01	0.005	0.04	0.02	0.02
LSD (P=0.05)	0.06	0.02	0.016	0.12	0.04	0.06
Boron levels (kg/ha)						
0	1.55	0.80	0.32	1.51	0.75	0.31
0.75	1.60	0.81	0.33	1.57	0.82	0.34
1.50	1.61	0.82	0.36	1.60	0.89	0.38
SEM +	0.02	0.01	0.005	0.04	0.02	0.02
LSD (P=0.05)	0.06	0.02	0.016	0.12	0.04	0.06
Absolute control						
Rest	1.60	0.65	0.32	1.51	0.70	0.25
SEM +	1.58	0.80	0.33	1.56	0.82	0.34
LSD (P=0.05)	0.03	0.02	0.006	0.05	0.02	0.05
	NS	0.06	NS	NS	0.04	0.09

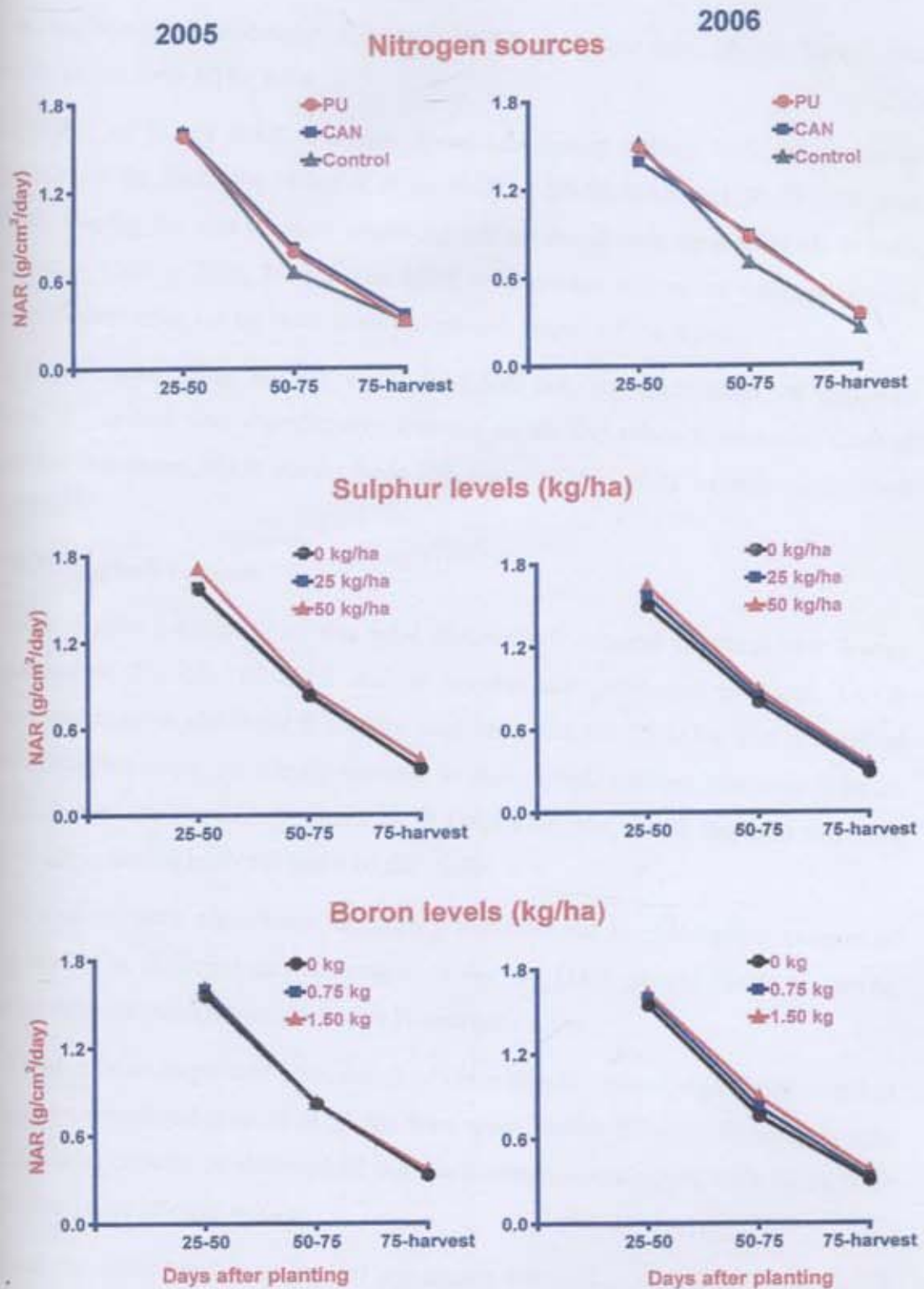


Fig. 7. Net assimilation rate of sunflower at different stages of crop growth as influenced by nitrogen sources, sulphur and boron levels

2006, S application statistically enhanced NAR but the rate of 25 kg/ha was statistically at par with 50 kg S/ha.

Effect of B on NAR was not found consistent during both the years of experimentation. In 2005, the effect of B on NAR at 25-50 DAS and 50-75 DAS was significant. During the last stage, a slight significant result was seen in NAR at both the doses of B. During 2006, B enhanced NAR with greater increment with application of 0.75 kg/ha than with 1.5 kg B/ha at all the growth stages of the crop.

Very encouraging results were recorded due to application of different treatments, as control was significantly inferior to all the other treatments. Control produced the minimum NAR during both the years of the study except 20-50 DAS during 2005.

4.1.1.7 Chlorophyll content

The results pertaining to the total chlorophyll content of sunflower leaves were recorded at 25, 50, 75 DAS and at harvest are presented in Table 14. A progressive increase in chlorophyll content was recorded till 75 DAS and it declined thereafter at harvest stage. An abrupt increase in chlorophyll content was seen from 25 to 50 DAS. It was on increasing pattern at 75 DAS also, but the % increase was very less, only 7-10%, during both the years of the study.

N sources were significant in causing a difference in chlorophyll content of sunflower leaves at different growth stages except 50 DAS during 2006. However, there was no definite trend observed due to N sources.

S which is an important component of chlorophyll, caused significant effect in enhancing the chlorophyll content at 25 kg S/ha, then further dose of 50 kg S/ha also increased the total content of chlorophyll but the increment was at par with 25 kg S/ha during both the years of crop raising.

B on the other hand, was proved significant even up to the higher level of 1.5 kg B/ha. The increment was more for the first dose than the higher one. A similar pattern was observed in the year 2006 as well.

Treatments	Chlorophyll content (mg/g fresh weight)											
	2005					2006						
	25 DAS	50 DAS	75 DAS	At harvest	25 DAS	50 DAS	75 DAS	At harvest	25 DAS	50 DAS	75 DAS	At harvest
Nitrogen sources												
PU	370.42	406.27	439.28	348.81	360.33	389.48	419.23	339.52				
CAN	385.94	388.35	432.93	364.80	375.40	393.15	435.48	360.00				
SEm ±	5.08	5.44	1.12	4.53	5.01	4.78	5.95	4.50				
LSD (P=0.05)	14.08	15.08	3.10	12.55	13.85	NS	16.48	11.58				
Sulphur levels (kg/ha)												
0	364.25	391.15	422.47	341.03	355.61	378.82	416.50	326.74				
25	383.63	398.96	433.58	360.58	370.71	390.22	427.29	356.74				
50	386.66	401.83	451.16	368.81	377.27	405.08	438.29	365.81				
SEm ±	6.22	6.66	7.85	5.54	6.01	6.25	6.82	5.25				
LSD (P=0.05)	17.22	18.44	21.77	15.37	16.64	17.31	18.89	14.51				
Boron levels (kg/ha)												
0	362.18	378.68	419.80	339.11	350.12	372.68	411.25	330.15				
0.75	380.22	395.17	436.97	355.02	365.21	389.25	425.70	349.25				
1.50	392.15	418.10	450.46	376.27	388.25	412.00	445.12	369.89				
SEm ±	6.22	6.66	7.85	5.54	6.01	6.25	6.82	5.25				
LSD (P=0.05)	17.22	18.44	21.77	15.37	16.64	17.31	18.89	14.51				
Absolute control	320.70	359.20	372.60	300.10	318.25	349.00	370.12	298.25				
Rest	378.18	397.31	435.74	356.80	367.86	391.31	427.35	349.76				
SEd ±	10.78	9.42	7.85	9.60	9.80	9.01	7.20	8.80				
LSD (P=0.05)	21.77	19.02	15.85	19.39	19.79	18.20	14.54	17.77				

The absolute control, which was devoid of any nutrient failed to beat any of the other nutrient treatment. It produced significantly the lowest chlorophyll in the leaves at all the growth stages of the crop during both the years of the experimentation.

4.1.2 Yield attributes

Various yield attributing characters of sunflower were recorded at harvest stage and have been set out in Table 15.

4.1.2.1 Capitulum size

Data on capitulum size of two crop seasons revealed that N through different sources were at par with each other irrespective of the year of the study.

S application resulted in larger size heads in both the years. Both the doses of S produced statistically higher capitulum diameter although the increase was more at lower dose i.e. 25 kg S/ha.

Capitulum size under B application remained statistically superior at both the doses during 2005 and 2006. In 2005, an increase up to 19% was noticed due to B application @ 0.75 kg/ha whereas the subsequent dose of 1.5 kg B/ha could bring a 5-6% increment only. During 2006, a sharper increase in capitulum diameter up to 16% was recorded due to 0.75 kg B/ha than previous year, while the response was lower at the higher dose of B.

In control plot, the performance of the crop was very poor when compared with rest of the treatments. All the treatments performed statistically better than control during both the seasons of the experimentation.

4.1.2.2 Number of seeds/capitulum

Application of various treatments registered higher number of seeds/capitulum in both the years as can be seen in Table 15.

In 2005, N through CAN produced significantly higher number of seeds/capitulum and the increase was about 35-40 seeds/capitulum. But contrarily, in 2006, no significant influence was seen and both the sources remained on par.

Table 15. Effect of nitrogen sources, sulphur and boron levels on yield attributes of sunflower

Treatments	2005						2006					
	Capitulum diameter (cm)	Number of seeds/capitulum	Seed weight/capitulum (g)	1000-seed weight (g)	Capitulum diameter (cm)	Number of seeds/capitulum	Seed weight/capitulum (g)	1000-seed weight (g)	Capitulum diameter (cm)	Number of seeds/capitulum	Seed weight/capitulum (g)	1000-seed weight (g)
Nitrogen sources												
PU	17.1	874.1	35.7	40.38	16.1	845.5	35.00	40.85				
CAN	17.2	835.6	36.1	41.20	17.2	856.1	35.22	40.25				
SEM ±	0.18	8.89	0.45	0.45	0.22	8.85	0.40	1.05				
LSD (P=0.05)	NS	24.66	NS	NS	NS	NS	NS	NS				
Sulphur levels (kg/ha)												
0	15.9	812.8	33.4	37.88	14.8	801.2	33.17	37.83				
25	17.0	848.4	36.8	41.53	17.3	850.2	35.10	40.73				
50	18.4	903.3	37.5	43.02	17.7	901.2	37.06	43.10				
SEM ±	0.20	10.90	0.56	0.78	0.26	11.02	0.49	1.62				
LSD (P=0.05)	0.66	30.21	1.56	2.16	0.72	30.52	1.42	4.45				
Boron levels (kg/ha)												
0	15.5	825.5	34.2	37.31	14.4	822.4	34.12	38.25				
0.75	17.4	857.7	35.8	40.43	17.2	852.4	35.11	40.15				
1.50	18.5	881.2	37.8	44.63	18.2	877.5	36.12	43.25				
SEM ±	0.20	10.90	0.56	0.78	0.26	11.02	0.49	1.62				
LSD (P=0.05)	0.66	30.21	1.56	2.16	0.72	30.52	1.42	4.45				
Absolute control	12.8	753.4	29.9	32.50	11.8	752.1	28.15	30.25				
Rest	17.1	854.8	35.9	40.79	16.6	850.8	35.11	40.55				
SED +	0.53	26.69	1.99	2.07	0.45	24.85	1.85	2.11				
LSD (P=0.05)	1.07	53.91	4.01	4.18	0.90	50.19	3.73	4.26				

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

S application markedly influenced the number of seeds/capitulum during both the years of the study. In 2005, the per cent increase due to S application @ 25 kg/ha was lower i.e. about 4.5% while it was a slightly higher at the higher dose about 6-8%. It means the response was up to 50 kg S/ha application. In 2006, the response of B was almost equal at both the doses and per cent increase noticed was around 5 both at 25 kg S/ha and 50 kg S/ha application.

The careful perusal of the data, shows that a significant increase in number of seeds/capitulum was noticed in all the treatments over control. The response noticed was about 13% at initial doses of S and B.

4.1.2.3 Seed weight (g)/capitulum

The response of sunflower to various treatments with regard to seed weight (g)/capitulum is shown in Table 15.

It is evident from the data that N sources failed to influence seed weight/capitulum in any of the year of the study. Seed weight/capitulum produced during both the years were statistically at par with each other.

S application produced more seed weight/capitulum during 2005. In 2006 also like the previous year, seed weight/capitulum was higher at both the doses. S doses were able to enhance the seed weight to nearly 2-4 g/capitulum with higher rate of increment at the first dose i.e. 25 kg S/ha. Second year followed the similar trend.

Response of B application was also significantly higher than control during both the years. Seed weight/capitulum was more or less similar in both the years of the study.

Seed weight/capitulum in the sunflower plant of control plot was minimum during both the years. A minimum increase up to 10% was seen due to application of different treatments which is quite higher.

4.1.2.4 1000-seed weight of sunflower

The response of sunflower to various treatment with regard to 1000-seed weight was recorded and presented in Table 15. The source of N could not make any significant difference in test weight of the sunflower crop during any of the years of the study.

S and B application proved to be statistically effective at both the doses, although the increment was higher at the first dose. During both the years an increment of almost 6-7% was seen in 1000-seed weight.

It was not surprising to see that sunflower seed weight was the lowest in control plot. All the treatments were better than control, both numerically and statistically.

4.1.3 Yields and harvest index (HI)

Data on seed yield, stover yield, total biological yield and harvest index have been set out in Table 16 for both the years of the experimentation.

4.1.3.1 Seed yield

Data on seed yield followed the trend set by yield attributing characters (Fig.8). In both the years, N application through different sources failed to cause an impact on seed yield. Although there was an increase of 60 kg and 90 kg seed yield/ha with CAN in 2005 and 2006, respectively but the differences caused were non-significant.

In both 2005 and 2006, S application caused a marked influence of seed yield. In 2005, an yield enhance of 168 kg/ha was noticed due to S application @ 25 kg/ha. At higher dose of S i.e. 50 kg/ha, the response was positive but the yield increment was only 45 kg/ha. In 2006, a sharp change in seed yield was observed, as first dose of S application @ 25 kg/ha with 160 kg/ha increment and for the subsequent dose of 50 kg S/ha yield enhancement was 105 kg/ha only.

B was also found to be a good nutrient as the highest total seed yield was recorded with B. During both the years, lower dose of B @ 0.75 kg/ha produced better response i.e. 5% yield enhancement and with B @ 1.5 kg/ha yielded as much as 100-180 kg/ha extra seed yield. The similar trend was followed during both the years.

Control plot where no inputs were applied produced the lowest yield. While all other treatments were significantly superior than control. yield enhancement was even up to 50% was experienced during both the years.

4.1.3.2 Stover yield

Table 16. Effect of nitrogen sources, sulphur and boron levels on seed yield, stover yield, biological yield and harvest index of sunflower

Treatments	2005				2006			
	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Nitrogen sources								
PU	1885.1	2096.3	3981.4	47.6	1825.5	1969.7	3795.3	48.0
CAN	1940.5	2181.9	4122.4	46.6	1918.9	2171.1	4090.0	46.8
SEM ±	31.06	24.02	34.11	0.64	30.36	22.03	73.10	0.55
LSD (P=0.05)	NS	66.53	94.48	NS	NS	61.02	202.48	NS
Sulphur levels (kg/ha)								
0	1787.6	2111.6	3899.2	45.8	1730.4	1920.6	3651.4	48.7
25	1955.8	2137.8	4093.7	47.7	1890.5	2090.3	3981.2	46.8
50	1995.1	2168.3	4163.3	47.9	1995.7	2200.4	4196.5	46.9
SEM ±	39.83	29.13	41.14	0.78	28.01	22.04	75.01	0.61
LSD (P=0.05)	110.04	NS	114.09	NS	77.03	72.08	210.17	NS
Boron levels (kg/ha)								
0	1825.4	2040.7	3866.1	47.2	1725.2	1932.9	3658.2	47.1
0.75	1901.6	2181.3	4082.9	46.5	1889.5	2102.9	3992.4	47.3
1.50	2011.9	2195.2	4207.1	47.7	2001.9	2175.5	4177.4	47.8
SEM ±	39.83	29.13	41.14	0.78	28.01	22.04	75.01	0.61
LSD (P=0.05)	110.04	80.67	114.09	NS	77.03	72.08	210.17	NS
Absolute control	1121.2	1870.5	2791.5	40.1	1098.1	1885.4	2770.1	39.6
Rest	1912.8	2139.1	4051.9	47.1	1872.2	2070.4	3942.7	47.4
SED +	97.31	56.01	111.02	1.93	85.02	29.02	83.02	0.80
LSD (P=0.05)	196.56	113.14	224.26	3.89	153.03	52.23	167.70	1.61

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

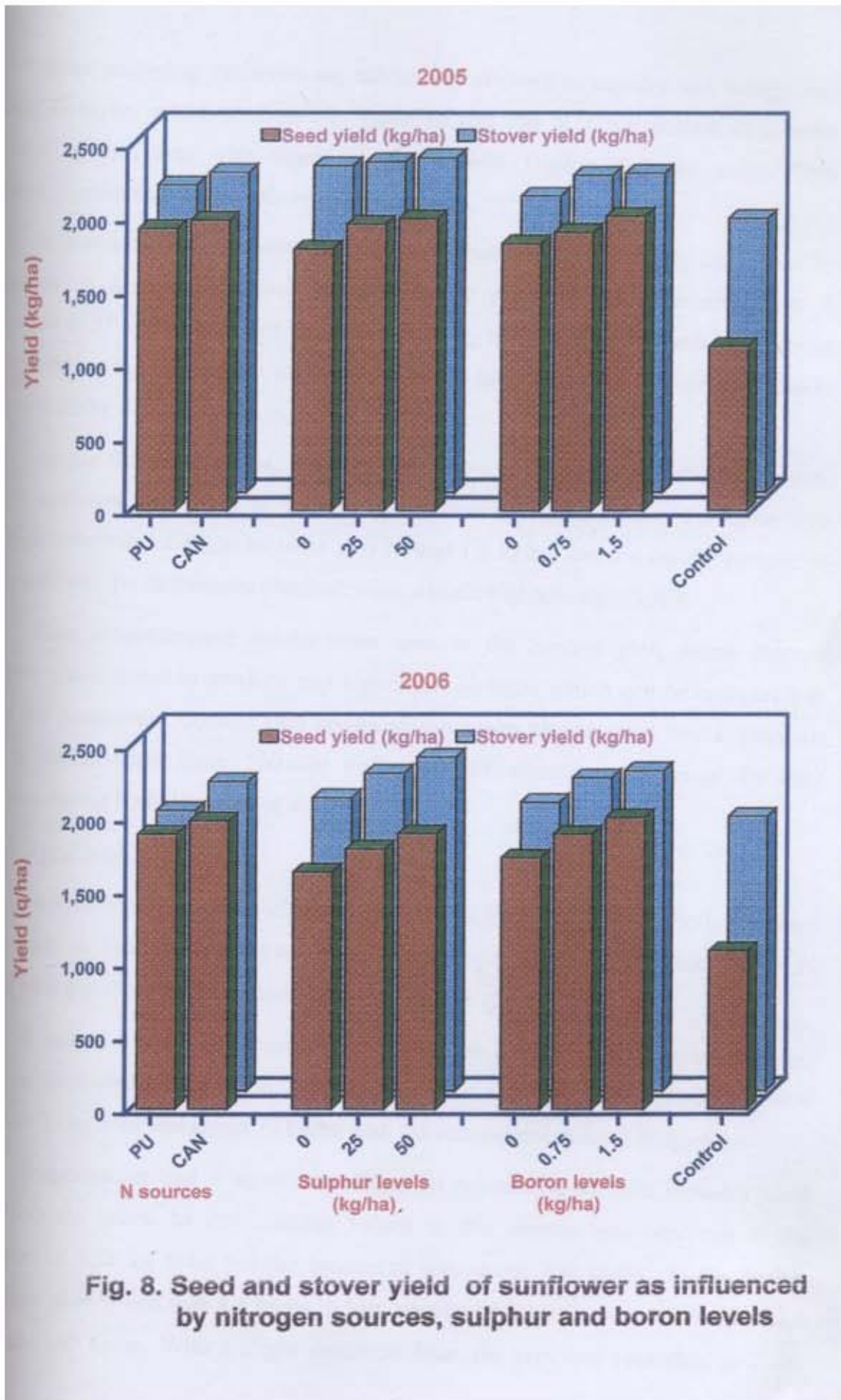


Fig. 8. Seed and stover yield of sunflower as influenced by nitrogen sources, sulphur and boron levels

After removing the seeds the stover was allowed to sun-dry and weight was recorded in kg/ha, which is shown in Table 16 and Fig. 8. CAN proved as a better source of N than urea with regard to stover yield. During both the years, CAN produced significantly higher stover yield than urea.

It is evident from the data that the stover yield was significantly influenced by application of S when recorded during both the years of the experimentation. S application at 25 kg/ha increased the stover yield up to 25 kg/ha, the further increment of S application i.e. 50 kg S/ha was also almost 30 kg/ha but it was found statistically at par with 25 kg S/ha application.

As per the expectations, B was unable to cause a significant effect on stover yield of sunflower during any of the year at both doses, whether 0.75 or 1.5 kg/ha. The stover yield recorded a slight increase at 0.75 and 1.5 kg/ha and the careful perusal of data reveals that the differences obtained were statistically non-significant.

Then predetermined results were seen in the control plot, where starved sunflower plants failed to produce any significant biomass which can be compared to any of the treatments. Control plot produced minimum stover yield and a quantum jump in stover yield from 200-400 kg/ha was experienced in various fertilizer treatments during both the years of study.

4.1.3.3 Total biological yield

Data on total biomass yield are presented in Table 16. During both the years of the study, it followed the trend of seed and stover yields. Difference due to N sources were significant with regard to total biological yield.

S proved to be a good source for vegetative growth and enhanced the total biological yield during 2005 and 2006 as well. The increase during 2005 was 100 kg/ha with 25 kg S/ha and about 70 kg/ha with the subsequent dose of 50 kg S/ha.

B application had a significant effect on production of total biomass yield during both the years. In 2005, higher values in this respect was observed at the application of 0.75 kg B/ha but the increment was about 200 kg/ha. At the further higher dose of B which was 1.5 kg/ha, a less amount of increase was observed which was nearly 150 kg/ha. With a slight deviation from the previous year data in 2006,

more sharp increment in total biomass yield was recorded at first dose of 0.75 kg B/ha which was nearly 300 while the rate of increase was lower at 1.5 kg B/ha.

Total biomass yield is the sum of seed and stover yield, which was significantly lower in absolute control plot than rest of the fertilizer treatments. During any of the year, absolute control plot could not produce total biomass yield equivalent to rest of the other treatments.

4.1.3.4 Harvest index (%)

Harvest index was not significantly affected due to application of various treatments as can be seen from Table 16. The effectiveness of any of the source of N could not be proved in this regard as HI of both the years of the study was at par with each other, although a slightly higher HI was observed with urea than CAN.

In 2005, harvest index was higher due to S application. A fairly constant increase was recorded at both the doses from 25 kg S/ha and 50 kg S/ha application, but the difference was non-significant. The response was somewhat lesser in 2006 also, where both the S doses failed to cause a very sharp change, although a significant effect was visible.

Among both the years of experimentation, B application was not effective in increasing HI. In both 2005 and 2006, B application @ 1.5 kg/ha remained statistically at par with 0.75 kg/ha. B could not enhance the HI significantly and the values were statistically at par with each other.

Following the trend up to now, absolute control plot produced significantly the lowest HI which was enhanced at all the other treatments of N, S and B during both the years of the study.

4.1.4 Quality parameters

The results on sunflower oil content, oil yield, protein content and fatty acid composition of sunflower oil along with oil quality components like iodine value, saponification value and acid value have been presented in Table 17-19.

4.1.4.1 Oil content (%) in seed

Table 17. Effect of nitrogen sources, sulphur and boron levels on oil content, oil yield and protein content of sunflower

Treatments	2005			2006		
	Oil content (%)	Oil yield (kg/ha)	Protein content (%)	Oil content (%)	Oil yield (kg/ha)	Protein content (%)
Nitrogen sources						
PU	47.05	883.25	20.60	44.51	833.90	20.15
CAN	46.21	919.86	21.15	43.91	859.77	20.45
SEM +	0.34	11.08	0.21	0.60	7.52	0.20
LSD (P=0.05)	NS	30.69	NS	NS	20.83	NS
Sulphur levels (kg/ha)						
0	45.82	826.23	20.05	43.93	755.67	19.89
25	46.90	928.57	20.85	44.98	849.23	20.15
50	47.18	949.86	21.76	46.64	935.59	20.89
SEM +	0.38	14.01	0.26	0.65	15.01	0.22
LSD (P=0.05)	1.05	38.80	0.72	1.80	41.57	0.60
Boron levels (kg/ha)						
0	45.10	833.61	19.61	44.11	760.99	19.90
0.75	46.68	896.50	21.26	45.21	854.22	19.64
1.50	48.11	974.55	21.77	46.22	925.30	21.39
SEM +	0.38	14.01	0.26	0.65	15.01	0.22
LSD (P=0.05)	1.05	38.80	0.72	1.80	41.57	0.60
Absolute control	44.40	492.12	15.75	44.85	482.35	14.85
Rest	46.63	901.55	20.88	45.18	846.83	20.31
SED +	0.49	14.11	0.42	0.68	17.01	0.40
LSD (P=0.05)	0.98	28.50	0.84	1.37	34.36	0.80

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

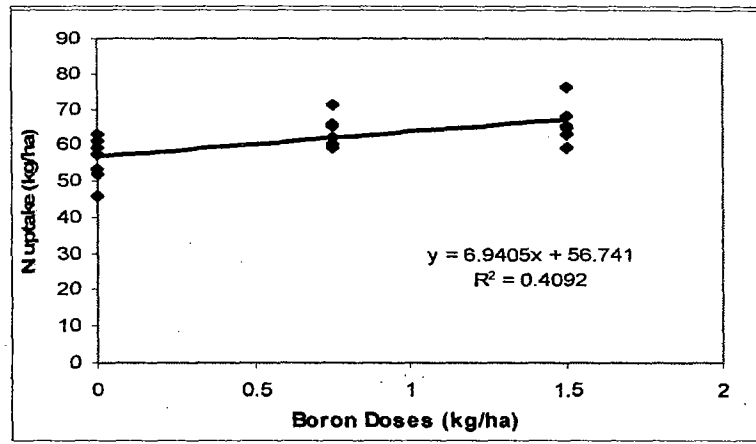
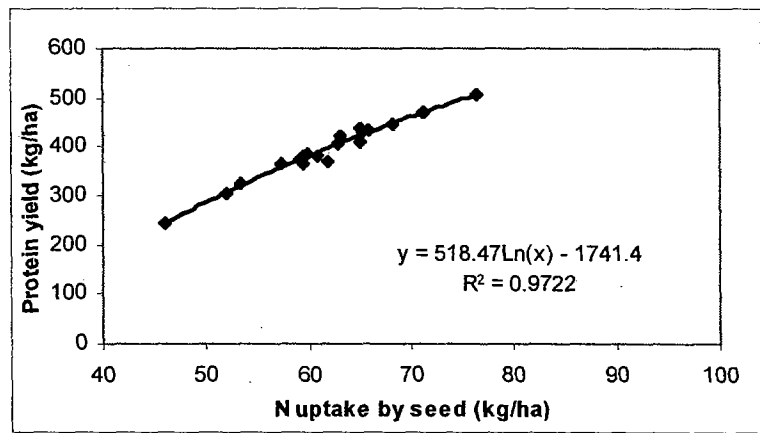
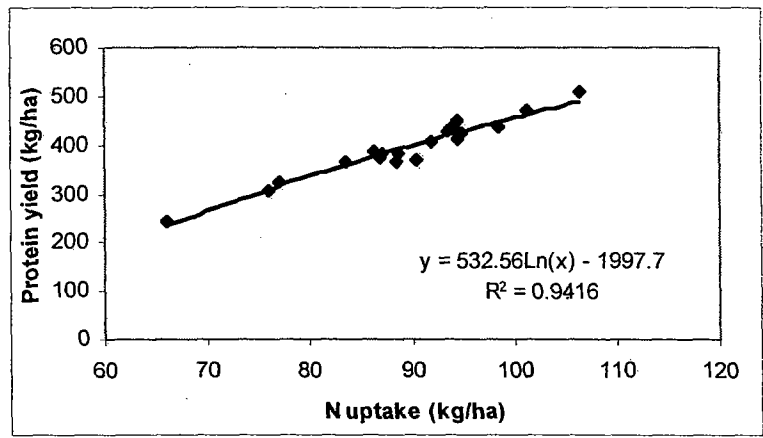


Fig. 9. Oil and protein yield relation with nutrient uptake

Results during both the years of the study postulated that various treatments had significant effect on oil content of sunflower seed. N application although enhanced oil content significantly, the sources could not leave any conspicuous impact on the oil content, both N sources being equally effective during both the years.

S application had a positive correlation with oil content during both the years of the study. Increasing levels of S increased the oil content simultaneously, the response was higher at the first dose as per the expectations. Depending upon the growth conditions and crop response, the increment in oil content enhanced up to 2.90% in 2005 which was about 5.82% in the next year compared to control.

Increasing levels of B resulted in corresponding increase in oil content of sunflower seeds. Interestingly, the increase was more than that of S application. In the first year, a boom of about 6.52% was noticed and during the second year, the enhancement was up to 4.78% compared to control (0 kg B/ha).

During both the years of the experimentation, the oil content of sunflower plants grown in deprived condition of control plot was substantially the lowest which was very well compensated by the application of different treatments.

4.1.4.2 Oil yield

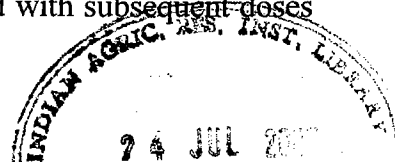
Effect of various treatments on oil yield of sunflower crop has been clear in the Table 17 and Fig. 9. Oil yield is calculated from values of oil content (%) and seed yield (kg/ha), it followed the same trend as oil content because both these parameters followed same pattern in 2005 and 2006.

N source selection i.e. CAN found to bring a reasonable statistical influence during both the year of the study.

S application had an ample effect on oil yield during both the years of experimentation. The response was higher during the second year, even up to 14.96% enhancement was recorded from the base value. This huge increment was not noticed in the first year which gave a 12.36% oil yield increment even when the same doses of S were applied.

B took a lead here also by producing higher oil yield than S treatments during both the years. A steady enhancement in oil yield was observed with subsequent doses

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of application of boron i.e. 0.75 and 1.5 kg/ha but the pace of increase was little higher during the first year.

Absolute control plot experienced statistically the lowest oil yield during both the years of the study and all the other treatments were quite superior than it.

Oil yield is significantly correlated with S application as it plays an important role in the biosynthesis of oil. The increasing oil yield with increase in S uptake can be quantified by following regression equation:

$$Y = 377.86 \text{ Ln}(x) + 267.5$$

$$R^2 = 0.754$$

Where, Y = Oil yield (kg/ha)

X = Total S uptake (kg/ha)

The coefficient of determination is 0.74 which confirmed a positive correlation between oil yield and S uptake during both the years of the study.

4.1.4.3 Protein content (%)

Data in Table 17 and Fig. 9 clearly indicated that the seed protein content was significantly influenced due to various fertilizer treatments. Both the N sources failed to give an impact on protein content of sunflower seeds.

S application at 50 kg/ha gave the highest protein content which was significantly superior to the previous level of 25 kg S/ha in 2005. Similar trend was observed in the next year also. During 2006, the protein content was slightly lower than 2005 at similar S doses.

B application registered the highest protein content @ 1.5 kg B/ha application in both 2005 and 2006. The rate of increase was higher between 0.75 and 1.5 kg/ha than at the first dose in 2006, while it was higher for the first dose during 2005.

Since all the treatments influenced markedly the protein content, absolute control plot recorded substantially the lowest protein content in the seed.

Protein yield was found to enhance with increasing N uptake. As our predictions N uptake was higher by seeds than by stover. The protein yield was more

correlated with N uptake in seed than total N uptake. The following equations quantify the individual relationships of total N uptake and N uptake in seeds:

A. Relationship of protein yield and total N uptake :

$$Y = 532.56 \text{ Ln } (x) - 1997.7$$

$$R^2 = 0.94$$

Where, Y = Protein yield (kg/ha).

x = Total N uptake (kg/ha)

B. Relationship of protein yield and seed N uptake

$$Y = 517.47 \text{ Ln } (x) - 1741.4$$

$$R^2 = 0.97$$

Where, Y = Protein yield (kg/ha)

x = N uptake by seeds (kg/ha)

4.1.4.4 Fatty acid composition and oil quality parameters

The major fatty acids like linoleic acid, oleic acid, palmitic acid and stearic acid were analysed during both the years of the study and the data are presented in Table 18 and 19.

N although is an important element in deciding the fatty acid composition of soil, however, the sources of N were not effective to cause a significant difference in any of the major fatty acid of sunflower oil.

Application of S proved to be non-significant to enhance the linoleic acid content during any of the year of study. In 2005, any of the S dose was unable to create a significant change in oleic acid content also while in 2006 a reverse trend was seen where S enhanced oleic acid significantly. A desirable effect of both doses of S was seen on saturated fatty acids (palmitic and stearic) during both years of the experimentation. S application reduced the content of saturated fatty acid significantly.

B application proved to be a useful choice in enhancing the quality of sunflower oil. It enhanced the unsaturated fatty acids both linoleic and oleic while reduced undesirable saturated fatty acids, both palmitic and stearic acids during 2005

Treatments	2005									
	Linoleic acid (%)	Oleic acid (%)	Palmitic acid (%)	Stearic acid (%)	Saponification Value	Iodine value	Acid value			
Nitrogen sources										
PU	65.40	21.36	7.42	4.86	193.84	148.10	206.72			
CAN	65.04	21.23	7.37	4.88	195.42	148.46	208.26			
SEM +	0.67	0.17	0.08	0.04	0.20	1.05	1.06			
LSD (P=0.05)	NS	NS	NS	NS	0.60	NS	NS			
Sulphur levels (kg/ha)										
0	63.86	21.06	8.60	5.34	194.15	146.33	207.90			
25	65.06	21.38	7.48	5.22	193.60	147.08	207.08			
50	66.76	21.45	6.11	4.07	189.45	151.43	207.50			
SEM +	1.17	0.21	0.10	0.05	0.25	1.15	1.21			
LSD (P=0.05)	NS	NS	0.28	0.15	0.69	3.18	NS			
Boron levels (kg/ha)										
0	62.25	20.76	7.93	5.51	194.45	145.43	209.06			
0.75	65.25	21.33	7.38	4.85	193.73	148.46	207.40			
1.50	68.16	21.79	6.88	4.26	192.72	150.95	206.01			
SEM +	1.17	0.21	0.10	0.05	0.25	1.15	1.21			
LSD (P=0.05)	NS	NS	0.28	0.15	0.69	3.18	NS			
Absolute control										
Absolute control	57.20	19.50	10.70	6.50	195.40	135.40	220.50			
Rest	65.22	21.29	7.39	4.87	193.63	148.28	207.49			
SEM +	2.03	0.27	0.11	0.06	0.62	2.15	2.44			
LSD (P=0.05)	4.10	0.54	0.22	0.12	1.25	4.34	4.92			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments		2006									
		Linoleic acid (%)	Oleic acid (%)	Palmitic acid (%)	Stearic acid (%)	Saponification Value	Iodine value	Acid value			
Nitrogen sources											
PU		66.28	21.65	7.92	5.32	189.99	152.20	199.86			
CAN		66.52	21.16	7.98	4.34	191.13	151.88	200.84			
SEM +		0.52	0.20	0.12	0.11	0.21	0.08	0.26			
LSD (P=0.05)		NS	NS	NS	0.33	0.63	0.23	NS			
Sulphur levels (kg/ha)											
0		65.89	20.98	8.67	4.89	191.62	150.72	202.89			
25		66.24	21.38	8.23	4.85	190.65	151.65	200.60			
50		67.19	21.84	6.96	4.75	189.42	153.77	197.47			
SEM +		1.34	0.21	0.13	0.14	0.30	0.14	2.15			
LSD (P=0.05)		NS	0.62	0.39	NS	0.87	0.38	NS			
Boron levels (kg/ha)											
0		64.92	21.09	8.24	5.26	191.85	150.57	201.37			
0.75		66.86	21.31	7.94	4.64	190.73	151.43	200.13			
1.50		67.49	21.82	7.69	4.61	189.11	151.98	199.56			
SEM +		1.34	0.21	0.13	0.14	0.30	0.14	2.15			
LSD (P=0.05)		NS	0.62	0.39	0.38	0.87	0.38	NS			
Absolute control											
Absolute control		59.87	20.12	9.72	7.62	194.61	138.57	212.61			
Rest		66.40	21.40	7.95	4.83	190.56	152.04	200.35			
SEM +		1.41	0.32	0.17	0.23	0.37	0.19	3.02			
LSD (P=0.05)		2.84	0.64	0.34	0.46	0.74	0.38	6.06			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

and 2006 also. All the treatments were significantly superior than absolute control during both the years of crop raising.

Results from other quality parameters of sunflower oil also encouraged the application of nutrients like N, S and B. N application enhanced the saponification value of sunflower oil but the difference was non-significant for the N sources. Both the N sources were equally effective. S application significantly reduced the saponification value during both the years of the study, while B was able to reduce saponification value significantly during both the years of the study. In 2005 as well as 2006, absolute control plot produced oil with maximum saponification value.

As far as iodine value is concerned, N sources were not able to cause an effective change. The values were higher with S application during both the years, while B was significant only in the first year, although all the values were significantly higher than the control.

When acid value was recorded, the highest number was for control. It reduced with N application but the difference due to N sources was non-significant. S also reduced acid value significantly during 2005 only while it was non-significant in 2006. Whereas, B had no correlation with acid value and failed to cause significant effect in any of the season.

4.1.5 Nutrient concentrations and their uptake

4.1.5.1 N concentration

N concentration in leaf and stem (at 25, 50, 75 DAS) and in root, stem, leaf and seed at harvest were estimated and are given in Table 20 and 21.

N concentration in different plant parts were significantly affected due to application of various treatments. A comparison of data on N concentration in two years showed almost equal values in both the years at all crop growth stages. N concentration was found to get reduced as plant grew from 25 DAS to harvest stage. Also the N concentration was higher in leaf than stem at 25, 50 and 75 DAS. At harvest stage, the highest N concentration was observed in seed followed by leaf, root and was the least in stem.

Treatment	N concentration (%)												
	2005												
	25 DAS			50 DAS			75 DAS			At harvest			
	Stem	Leaf		Stem	Leaf		Stem	Leaf		Root	Stem	Leaf	Seed
Nitrogen sources													
PU	0.43	4.46		0.37	4.19		0.33	2.97		0.506	0.172	2.33	3.25
CAN	0.45	4.60		0.39	4.33		0.35	3.10		0.507	0.175	2.48	3.29
SEM ±	0.003	0.04		0.04	0.03		0.003	0.03		0.005	0.002	0.03	0.03
LSD (P=0.05)	0.009	0.12		NS	0.06		0.009	0.09		NS	NS	NS	NS
Sulphur levels (kg/ha)													
0	0.43	4.29		0.37	4.07		0.30	2.67		0.455	0.170	2.19	3.22
25	0.44	4.44		0.38	4.23		0.32	2.87		0.502	0.174	2.34	3.27
50	0.46	4.86		0.41	4.50		0.37	3.57		0.563	0.176	2.68	3.32
SEM ±	0.004	0.05		0.05	0.05		0.005	0.03		0.007	0.001	0.03	0.03
LSD (P=0.05)	0.012	0.14		NS	0.14		0.015	0.10		0.021	0.003	0.09	0.09
Boron levels (kg/ha)													
0	0.42	4.48		0.35	4.08		0.32	2.80		0.482	0.166	2.26	3.21
0.75	0.44	4.52		0.38	4.27		0.35	3.05		0.510	0.174	2.41	3.27
1.50	0.47	4.65		0.41	4.44		0.37	3.24		0.528	0.180	2.55	3.33
SEM ±	0.004	0.05		0.05	0.05		0.005	0.03		0.007	0.001	0.03	0.03
LSD (P=0.05)	0.012	0.14		NS	0.14		0.015	0.10		0.021	0.003	0.09	0.09
Absolute control													
Absolute control	0.36	3.98		0.29	3.52		0.20	2.05		0.330	0.150	1.56	2.96
Rest	0.44	4.53		0.38	4.26		0.34	3.03		0.506	0.173	2.40	3.27
SED +	0.01	0.06		0.06	0.07		0.06	0.09		0.01	0.004	0.08	0.05
LSD (P=0.05)	0.02	0.12		NS	0.14		0.12	0.18		0.02	0.008	0.16	0.10

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Table 21. Effect of nitrogen sources, sulphur and boron levels on N concentration in different plant parts of sunflower plant at various growth (2006)

Treatments	N concentration (%)											
	2006											
	25 DAS			50 DAS			75 DAS			At harvest		
	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Root	Stem	Leaf	Seed
Nitrogen sources												
PU	0.44	4.55	0.45	4.24	0.37	2.68	0.17	2.33	0.56	0.17	2.33	3.16
CAN	0.45	4.87	0.48	4.36	0.40	2.47	0.19	2.12	0.58	0.19	2.12	3.34
SEm ±	0.01	0.03	0.03	0.04	0.001	0.02	0.01	0.02	0.02	0.01	0.02	0.04
LSD (P=0.05)	0.03	0.09	NS	0.11	0.003	0.06	NS	0.06	NS	NS	0.06	0.12
Sulphur levels (kg/ha)												
0	0.42	4.44	0.38	4.20	0.35	2.59	0.17	2.09	0.49	0.17	2.09	3.11
25	0.44	4.56	0.49	4.30	0.39	2.72	0.18	2.27	0.57	0.18	2.27	3.26
50	0.47	5.13	0.53	4.42	0.41	2.97	0.20	2.45	0.63	0.20	2.45	3.39
SEm ±	0.02	0.04	0.05	0.05	0.005	0.03	0.001	0.04	0.002	0.001	0.04	0.04
LSD (P=0.05)	NS	0.12	0.15	0.16	0.015	0.10	0.002	0.12	0.006	0.002	0.12	0.11
Boron levels (kg/ha)												
0	0.42	4.33	0.44	4.15	0.34	2.57	0.16	2.15	0.47	0.16	2.15	3.02
0.75	0.45	4.78	0.45	4.30	0.38	2.80	0.19	2.20	0.59	0.19	2.20	3.31
1.50	0.47	5.02	0.49	4.47	0.42	2.31	0.21	2.35	0.63	0.21	2.35	3.44
SEm ±	0.02	0.04	0.05	0.05	0.005	0.03	0.001	0.04	0.002	0.001	0.04	0.04
LSD (P=0.05)	NS	0.12	0.15	0.16	0.015	0.10	0.002	0.12	0.006	0.002	0.12	0.11
Absolute control	0.37	4.07	0.27	4.02	0.21	2.10	0.14	1.66	0.39	0.14	1.66	2.85
Rest	0.44	4.71	0.46	4.30	0.38	2.56	0.18	2.27	0.56	0.18	2.27	3.25
SEd +	0.01	0.05	0.09	0.08	0.05	0.09	0.02	0.08	0.04	0.02	0.08	0.05
LSD (P=0.05)	0.02	0.15	0.18	0.16	0.10	0.18	0.04	0.16	0.08	0.04	0.16	0.10

PU = Prilled urea, CAN = Calcium ammonium nitrate; DAS = Days after sowing



Effect of nitrogen fertilization and its sources on sunflower at vegetative growth



Effect of nitrogen fertilization and its sources on sunflower at flowering stage



Effect of nitrogen sources on growth and development of sunflower

At 25 DAS, N application resulted in higher accumulation of N in stem and leaves. Out of the two different sources, N concentration was found to be significantly higher with CAN. Various levels of S also enhanced the N concentration in the plant during both the years of the study. A significant increment in N concentration with B application was seen in both stem and leaves, while all the treatments were superior than control in both 2005 and 2006.

At 50 DAS, higher N concentration was recorded due to CAN application than urea. S application @ 25 and 50 kg/ha were able to enhance N concentration than control, while the N concentration in stem and leaves at 50 kg S/ha remained on par with 25 kg S/ha. Similar trend was also seen with B application. During 2005 both the sources of N were found to be statistically at par with each other, while in 2006, stem N concentration increased non-significantly while leaf N concentration at 50 kg S/ha remained statistically at par with S application @ 25 kg/ha.

At 75 DAS, the trend became linear with respect to N concentration and nutrient application. N application, of course enhanced N concentration in both parts during both the years. Here also, CAN prove to be a better source than urea. Increasing level of S increased N concentration in different plant parts. The response was higher at lower dose of S application during both the years of the study. B application had a similar effect during both the years. Increasing doses resulted in subsequent increase in N concentration. All the fertilizer treatments proved significantly superior than the absolute control plot.

At harvest stage, control resulted in minimum N accumulation in different plant parts. N application resulted in higher N concentration in different plant parts. In 2005, in root and stem, the N concentration due to different sources remained statistically non-significant. While in 2006, in leaf and seed, CAN application accumulated higher N concentration. S application resulted in higher N concentration in all the parts and the difference was significant at both the doses. B application was able to enhance the N concentration in roots at both the doses, in stem and leaf and it produced significantly higher results while in seed, the N concentration enhancement was up to the application of 0.75 kg B/ha and the response remained statistically at par with 1.5 kg B/ha.

4.1.5.2 Nitrogen uptake

N uptake by different parts of the sunflower plant is presented in Table 22-23 and Fig. 10-12. During the year 2005 and 2006, in almost all the stages uptake was more in the first year than in the second year following the pattern set by concentration and dry matter accumulation. At all the stages in two years of the study, control plot recorded the lowest uptake of N. Whereas all the treatments on nutrient management performed better than control with regard to N uptake.

At 25 DAS, different sources of N could not make any statistically significant difference during any of the years of the study except in stem in 2005. S application at 25 and 50 kg/ha proved a significant beneficial effect in higher N uptake. N uptake by leaf was more than that by the stem. During 2005, N uptake in leaves at 50 kg S/ha was significantly higher and remained superior than 25 kg S/ha, while both the doses of S were beneficial in subsequent increment of N uptake in stem during both the years of the study. A similar trend like S was also seen in case of B where B application @ 1.5 kg/ha helped in maximum N uptake during 2005 and 2006 as well. During 2006, N uptake in leaves at the application of 1.5 kg B/ha was statistically superior than 0.75 kg B/ha, while a linear increase was observed in N uptake by stem by both the B doses during both the years. Absolute control was a complete failure and resulted in minimum N uptake in different plant parts of sunflower.

At 50 DAS, N uptake was significantly higher in different plant parts of sunflower than absolute control. It also followed the same pattern as that at 25 DAS but N uptake ratio between leaf and stem became wider about 6:1 at 50 DAS from nearly 4:1 at 25 DAS. It shows more deviation of N towards leaves at later stages. N sources could not make any significant difference in N uptake in either part during either year. A sharp and significant difference in N uptake by both leaves and stem was noticed at different doses of S during both the years. Similarly, B also played important role in significantly increasing the N uptake where the response was more at the first dose i.e. 0.75 kg B/ha.

At 75 DAS also, absolute control treatment was far inferior than other treatments with the lowest N uptake in them. In both the years, S had a significant effect in enhancing the total N uptake. The N uptake ratio in leaf:stem again shranked

Table 22. Effect of nitrogen sources, sulphur and boron levels on N uptake by sunflower plant parts at various growth stages (2005)

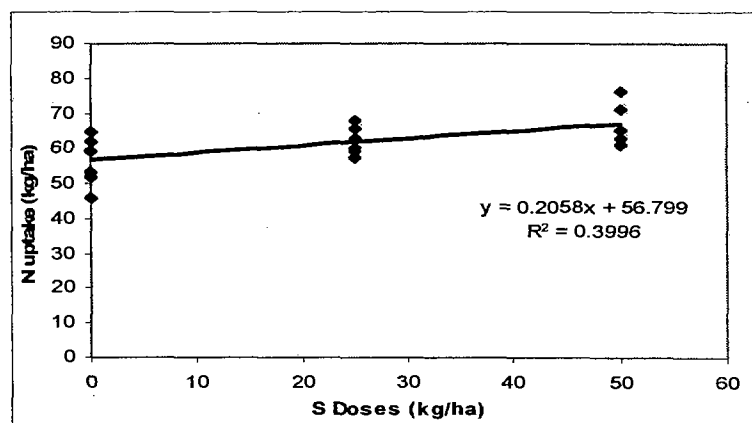
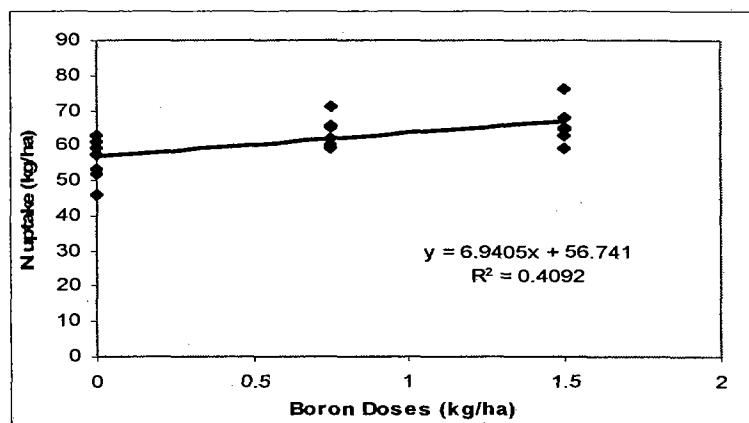
Treatments	N uptake (mg/plant)													
	2005													Total
	25 DAS			50 DAS			75 DAS			At harvest				
	Leaf	Stem		Leaf	Stem		Leaf	Stem		Root	Leaf	Stem	Seed	
Nitrogen sources														
PU	57.22	17.62		379.68	60.25		943.32	134.91		77.13	601.26	84.51	1169.42	1855.19
CAN	59.06	19.23		388.60	61.68		1014.24	143.03		79.83	617.26	86.28	1190.66	1894.20
SEm +	0.71	0.21		4.79	0.82		11.16	1.84		0.97	2.46	1.07	9.97	8.14
LSD (P=0.05)	NS	0.58		NS	NS		30.92	5.10		NS	6.84	NS	27.64	22.57
Sulphur levels (kg/ha)														
0	56.18	15.60		357.65	50.51		839.32	115.50		68.14	508.57	78.99	959.92	1547.47
25	58.20	19.00		378.16	56.13		967.68	135.91		76.50	607.89	85.39	1001.16	1694.43
50	60.06	20.77		416.60	76.25		1129.33	165.50		90.79	711.33	91.80	1579.05	2382.17
SEm +	0.86	0.23		5.87	1.00		13.67	2.26		1.18	9.97	1.32	14.10	17.27
LSD (P=0.05)	2.41	0.69		16.27	2.79		37.91	6.27		3.29	27.64	3.66	39.05	47.80
Boron levels (kg/ha)														
0	55.14	15.58		349.47	45.14		870.34	118.21		70.94	532.82	72.50	1103.06	1708.17
0.75	58.39	18.31		386.78	66.20		958.10	141.35		79.06	601.08	86.65	1178.67	1866.19
1.50	60.90	21.52		416.16	71.37		1107.89	157.36		85.42	693.89	97.04	1259.00	2049.62
SEm +	0.86	0.23		5.87	1.00		13.67	2.26		1.18	9.97	1.32	14.10	17.27
LSD (P=0.05)	2.41	0.69		16.27	2.79		37.91	6.27		3.29	27.64	3.66	39.05	47.80
Absolute control	32.64	10.47		278.43	26.42		455.92	61.48		45.21	245.23	54.02	897.16	1196.41
Rest	58.14	18.45		384.13	60.97		978.77	138.97		78.48	609.26	85.39	1180.04	1874.69
SEd +	1.79	0.40		6.38	1.43		13.50	12.58		2.96	14.43	2.06	18.96	42.27
LSD (P=0.05)	3.61	0.80		12.88	2.88		27.27	25.41		5.97	29.14	4.16	38.29	85.38

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

(2006)

Treatments	N uptake (mg/plant)													
	2006													
	25 DAS			50 DAS			75 DAS			At harvest				
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total	
Nitrogen sources														
PU	57.04	14.92	350.15	61.49	840.67	134.82	80.55	554.49	80.81	1292.24	1927.54			
CAN	61.25	15.56	364.73	70.83	932.33	153.93	86.12	579.06	92.97	1062.83	1734.86			
SEM ±	2.11	0.03	5.61	3.87	9.49	4.10	2.39	5.33	4.17	9.24	5.33			
LSD (P=0.05)	NS	NS	NS	NS	26.32	11.36	NS	14.79	NS	25.62	14.79			
Sulphur levels (kg/ha)														
0	54.24	11.83	324.19	47.81	790.40	123.37	69.57	480.35	73.96	1074.41	1628.72			
25	59.47	16.62	342.27	66.32	874.92	143.86	82.84	562.15	86.34	1190.13	1838.62			
50	63.72	18.12	405.86	84.37	994.41	165.83	97.59	657.81	100.37	1268.05	2026.23			
SEM ±	3.08	0.04	6.53	3.37	14.38	10.17	5.87	13.67	4.72	8.30	6.42			
LSD (P=0.05)	8.54	0.12	18.11	10.45	39.87	28.19	16.27	37.91	13.29	23.02	17.82			
Boron levels (kg/ha)														
0	51.39	12.69	314.59	57.20	779.35	123.83	60.93	504.89	68.40	1048.97	1622.26			
0.75	57.64	14.98	357.33	61.87	890.91	144.41	87.38	557.84	86.11	1186.47	1830.42			
1.50	68.41	18.90	400.41	79.43	989.47	165.49	101.69	637.59	106.16	1297.17	2040.92			
SEM ±	3.08	0.04	6.53	3.37	14.38	10.17	5.87	13.67	4.72	8.30	6.42			
LSD (P=0.05)	8.54	0.12	18.11	10.45	39.87	28.19	16.27	37.91	13.29	23.02	17.82			
Absolute control	32.48	10.97	287.46	28.43	469.34	73.89	49.83	347.68	59.34	891.89	1298.91			
Rest	59.14	15.52	357.44	66.16	886.57	144.37	83.33	566.77	86.89	1177.53	1831.19			
SED ±	3.24	0.06	10.17	8.30	14.38	11.06	6.80	19.34	6.23	33.50	23.69			
LSD (P=0.05)	6.54	0.12	20.54	16.76	29.04	22.34	13.73	39.06	12.58	67.60	47.85			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing



$$N_{\text{uptake}} = 52.5363 + 0.191549 \cdot S_{\text{applied}} + 6.473324 \cdot B_{\text{applied}}$$

$$R^2 = 0.75$$

Fig.12. N uptake in sunflower seed due to S and B levels

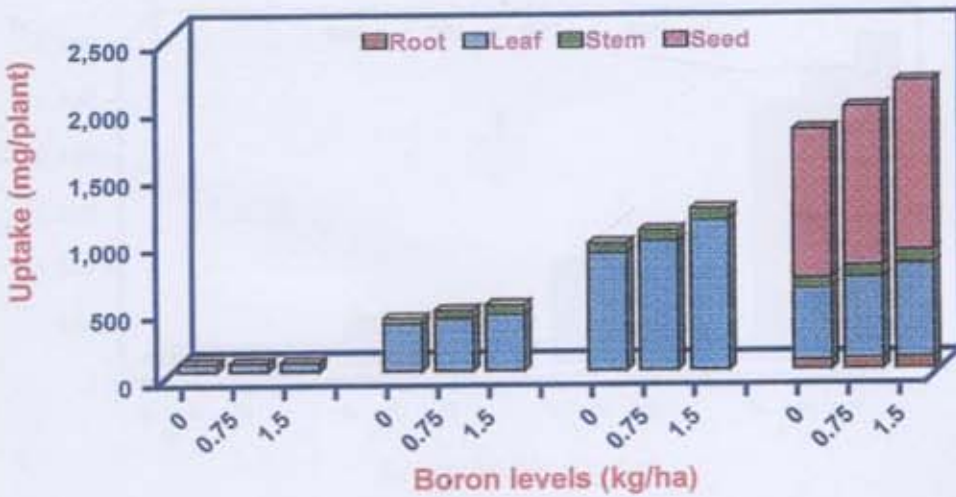
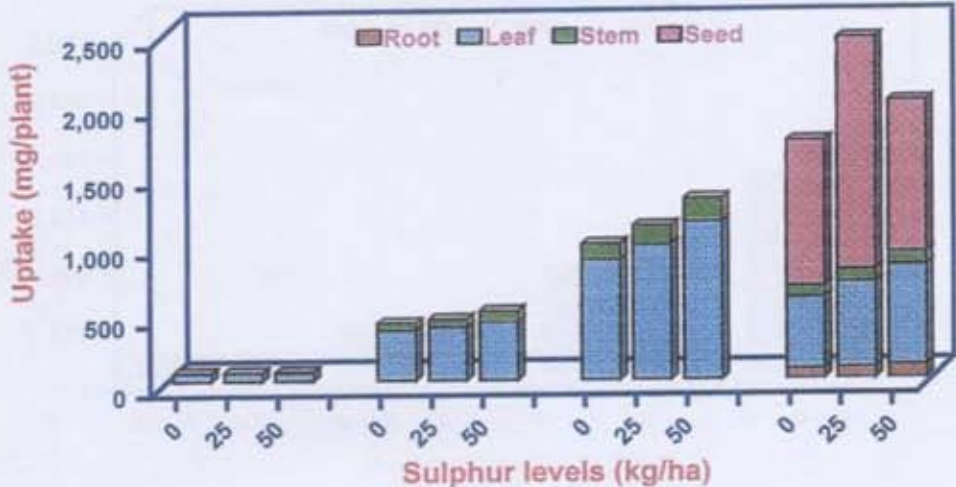
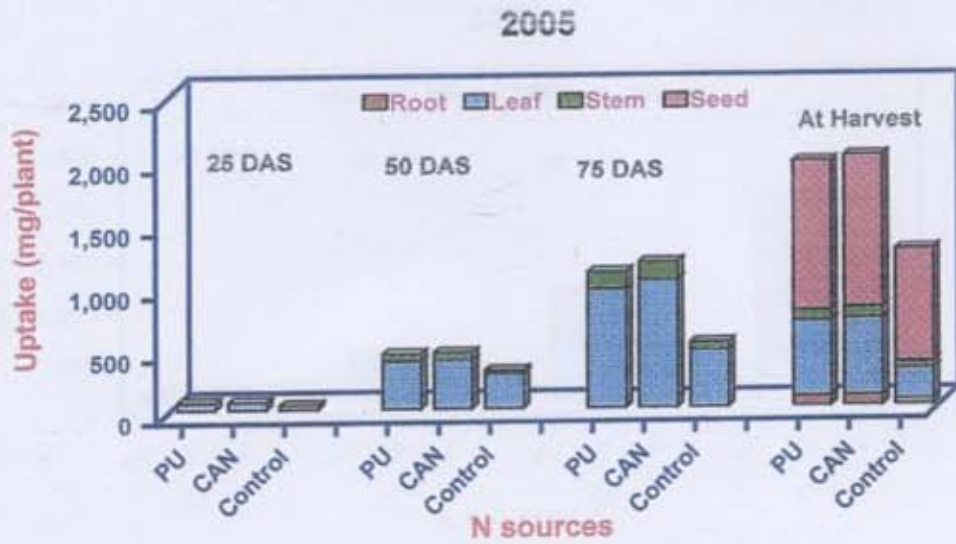


Fig. 10. Nitrogen uptake per plant by sunflower as influenced by nitrogen sources, sulphur and boron levels (2005)

2006

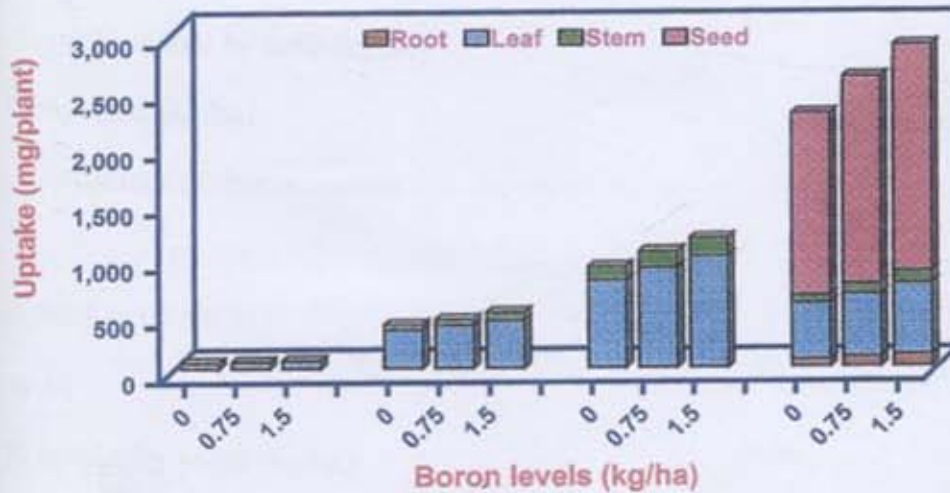
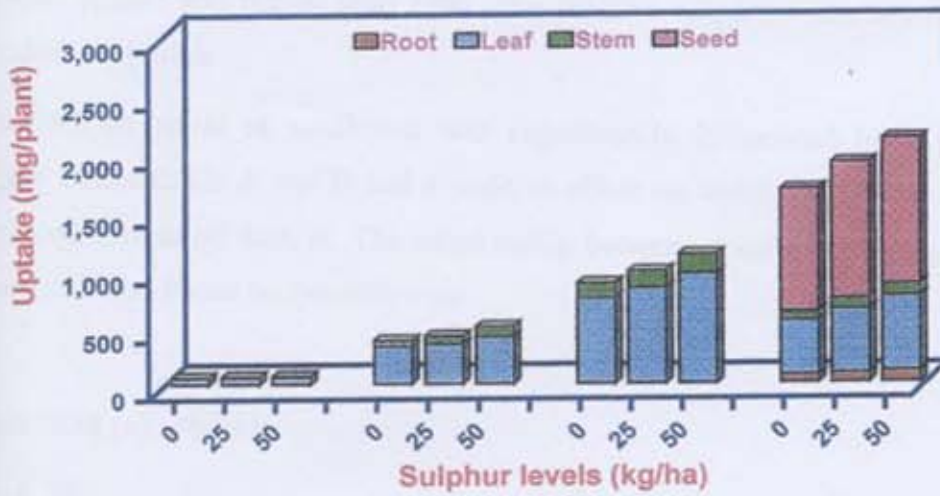
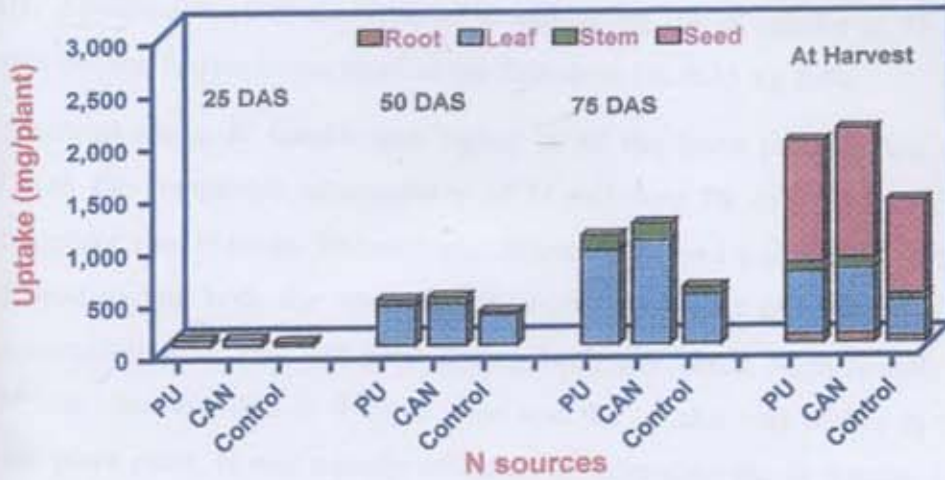


Fig. 11. Nitrogen uptake per plant by sunflower as influenced by nitrogen sources, sulphur and boron levels (2006)

to about 4:1. Application of B also helped in enhancing the N uptake at 75 DAS in both the years but the increase was more at the first dose i.e. 0.75 kg B/ha.

At harvest stage, N uptake was higher in all the plant parts during the first year. Seed was the maximum accumulator of N followed by leaf and shoot while minimum N uptake was in roots. Interestingly, N source caused a significant difference in leaf and seed during both the years. CAN proved to be an important source for higher N accumulation in leaf and seed during both the years. Significantly higher uptake of N was observed due to S application and the uptake was higher in the first year in all the plant parts. B was equally effective in enhancing the N uptake. In 2005, the average total uptake was higher than 2006. The positive response was recorded up to the higher dose of B also.

N uptake by seeds of sunflower was significantly influenced by S and B doses. Both the elements i.e. S and B had a positive effect on uptake of N. But S was found to be more correlated than B. The relationship between total N uptake and the different doses of S and B can be quantified as:

(A) S doses:

$$Y = 0.2058 (x) - 56.741$$

$$R^2 = 0.39$$

Where, Y = Total N uptake by seed (kg/ha)

x = Doses of S (kg/ha)

R² = Coefficient of determination

(B) B doses:

$$Y = 6.9405 (x) + 56.741$$

$$R^2 = 0.40$$

Where, Y = N uptake by seeds (kg/ha)

X = Doses of B (kg/ha)

The combined multiple regression equation can be written as:

$$\text{N uptake} = 52.53 + 0.19 \text{ S applied} + 6.47 \text{ B applied}$$

$$R^2 = 0.75$$

4.1.5.3 Phosphorus concentration

Total P concentration in stem and leaves of sunflower plants at 25, 50, 75 DAS and in root, stem, leaves and seed at harvest stage have been set out in Table 24 and 25. Data on P concentration indicated almost similar values in both the crop seasons. P concentration was found to decrease with the advancement of time with plants at 25 DAS having higher P than those at harvest stage.

At 25 DAS, no significant difference was recorded in P concentration between the two sources of N. Both urea and CAN were found to be equally effective during both the years. Application of S significantly influenced the P concentration in stem and leaves in both 2005 and 2006. The increase was almost steady with both the doses of S. Different treatments of B also caused marked influence on P concentration. In 2005, the increment was more in stem than leaves at the rate of 0.75 kg B/ha than at higher B dose. But in 2006, at 1.5 kg B/ha the P concentration in leaves remained at par with 0.75 kg B/ha and a similar trend was seen for stem like that in 2005.

At 50 DAS, the ratio of P concentration in stem and leaves became narrower but stem was the main P accumulator here also. All the treatments were significantly superior with regards to P concentration than control during both the years of the study. N sources were unable to give a significant difference in any of the year. While S and B applications had a significant influence on P concentration in both stem and leaves. The pace of increment remained almost same at both the doses of nutrients and a similar trend was noticed during both the years of experimentation.

At 75 DAS, the ratio of P concentration between stem and leaf narrowed down to 1.16 from 1.32 at 50 DAS. Stem accumulated relatively higher P concentration than leaves during both the years. N sources, here also could not make much significant difference in leaf P concentration, although CAN was slightly better than urea but statistically at par with each other. Different doses of S and B were effective in enhancing the P concentration in different plant parts. The response was more clear at first dose than the next higher dose. Similar pattern was followed during both the years of the study.

Treatments	P concentration (%)												
	2005												
	25 DAS			50 DAS			75 DAS			At harvest			
	Stem	Leaf		Stem	Leaf		Stem	Leaf		Root	Stem	Leaf	Seed
Nitrogen sources													
PU	0.44	0.39		0.36	0.33		0.31	0.29		0.15	0.28	0.24	0.85
CAN	0.47	0.40		0.37	0.34		0.32	0.29		0.17	0.29	0.26	0.87
SEM +	0.005	0.005		0.003	0.004		0.003	0.004		0.003	0.003	0.002	0.008
LSD (P=0.05)	NS	NS		NS	NS		NS	NS		NS	0.009	0.006	NS
Sulphur levels (kg/ha)													
0	0.43	0.36		0.32	0.31		0.28	0.27		0.14	0.24	0.22	0.83
25	0.45	0.40		0.36	0.35		0.33	0.29		0.17	0.29	0.26	0.86
50	0.48	0.45		0.41	0.36		0.36	0.31		0.19	0.33	0.28	0.89
SEM +	0.006	0.005		0.004	0.004		0.004	0.004		0.004	0.004	0.004	0.01
LSD (P=0.05)	0.018	0.015		0.012	0.012		0.012	0.012		0.012	0.012	0.012	0.03
Boron levels (kg/ha)													
0	0.39	0.38		0.34	0.30		0.30	0.27		0.14	0.25	0.21	0.82
0.75	0.46	0.40		0.35	0.34		0.33	0.30		0.17	0.29	0.26	0.86
1.50	0.51	0.43		0.39	0.38		0.35	0.31		0.19	0.32	0.29	0.89
SEM +	0.006	0.005		0.004	0.004		0.004	0.004		0.004	0.004	0.004	0.01
LSD (P=0.05)	0.018	0.015		0.012	0.012		0.012	0.012		0.012	0.012	0.012	0.03
Absolute control													
Absolute control	0.31	0.25		0.26	0.22		0.20	0.17		0.08	0.18	0.11	0.73
Rest	0.45	0.40		0.36	0.34		0.32	0.29		0.16	0.28	0.25	0.86
Sed +	0.015	0.014		0.010	0.010		0.009	0.007		0.005	0.009	0.007	0.02
LSD (P=0.05)	0.030	0.028		0.020	0.020		0.018	0.014		0.010	0.018	0.014	0.04

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	P concentration (%)												
	2006												
	25 DAS			50 DAS			75 DAS			At harvest			
	Stem	Leaf		Stem	Leaf		Stem	Leaf		Root	Stem	Leaf	Seed
Nitrogen sources													
PU	0.43	0.38		0.36	0.31		0.30	0.28		0.15	0.26	0.23	0.83
CAN	0.44	0.41		0.37	0.33		0.32	0.29		0.17	0.28	0.26	0.85
SEM +	0.05	0.05		0.03	0.04		0.002	0.04		0.01	0.01	0.002	0.006
LSD (P=0.05)	NS	NS		NS	NS		0.006	NS		NS	NS	0.005	0.018
Sulphur levels (kg/ha)													
0	0.41	0.35		0.32	0.30		0.27	0.26		0.13	0.23	0.22	0.81
25	0.44	0.40		0.35	0.33		0.32	0.29		0.17	0.27	0.24	0.85
50	0.47	0.45		0.42	0.35		0.35	0.31		0.19	0.32	0.26	0.87
SEM +	0.006	0.006		0.03	0.04		0.05	0.03		0.05	0.03	0.01	0.02
LSD (P=0.05)	0.018	0.018		NS	NS		NS	NS		NS	NS	0.03	0.06
Boron levels (kg/ha)													
0	0.40	0.37		0.33	0.28		0.29	0.25		0.13	0.23	0.19	0.81
0.75	0.45	0.41		0.36	0.33		0.31	0.28		0.17	0.28	0.25	0.84
1.50	0.49	0.44		0.40	0.37		0.34	0.32		0.20	0.31	0.28	0.89
SEM +	0.006	0.006		0.03	0.04		0.05	0.03		0.05	0.03	0.01	0.02
LSD (P=0.05)	0.018	0.018		NS	0.11		NS	0.09		NS	NS	0.03	0.06
Absolute control	0.32	0.24		0.25	0.23		0.17	0.16		0.09	0.17	0.10	0.75
Rest	0.44	0.40		0.36	0.32		0.33	0.28		0.16	0.27	0.24	0.84
SED +	0.07	0.11		0.04	0.05		0.08	0.08		0.07	0.09	0.08	0.04
LSD (P=0.05)	0.14	0.22		0.08	NS		0.16	0.16		0.14	NS	0.16	0.08

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

At harvest stage, seed accumulated the highest P concentration during both the years of the study, followed by stem, leaf and minimum in roots. In roots, N sources were not able to cause any significant difference during any of the seasons. S application was effective to enhance P concentration during both the years, the increment was, of course, more with the initial dose of 25 kg S/ha. B also markedly influenced the P concentration in roots. During both the years of the study, a reasonably good increase in P concentration of roots was noticed with B @ 0.75 kg/ha. The increment was continued till the next dose also but the pace reduced to almost half. Above all, various fertilizer treatments were far better than absolute control which accumulated the lowest P concentration in roots. The ratio of P concentration between stem and leaf declined further from the previous observations. In 2005, both stem and leaves produced significantly higher P concentration where CAN was applied but in 2006, CAN was significant source for P concentration in leaves only. S and B applications played similar role in P concentration enhancement as mentioned above. All the fertilizer treatments were significantly superior to absolute control during both the years of the study.

4.1.5.4 P uptake

P uptake by stem and leaves (at 25, 50, 75 DAS) and all parts of the plant separately at harvest is presented in Table 26-27 and Fig. 13.

The uptake of P by sunflower followed more or less the same trend set out by dry matter accumulation, since no P applied from outside as fertilizers. At all the stages, higher uptake was recorded in the first year as compared to the second year as it is evident from the data. All the fertilizer treatments resulted better than unfertilized control at all the stages in both the crop seasons. P uptake by leaves increased up to 75 DAS and declined thereafter at harvest stage, but a steady increase was observed by stem with a sharp rate between 25-50 DAS and 50-75 DAS.

At 25 DAS, P uptake by leaves was almost 3 times higher than that of stem. The difference caused by different N sources in P uptake by different plant parts was non-significant during both the seasons. Different levels of S caused significant difference in P uptake. A linear relationship was recorded between 2 levels of S and P uptake during both the years. For B, both the doses i.e. 0.75 kg/ha and 1.5 kg/ha were

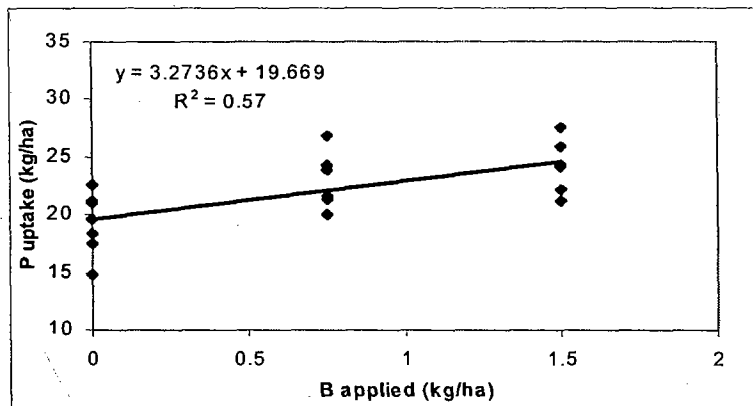
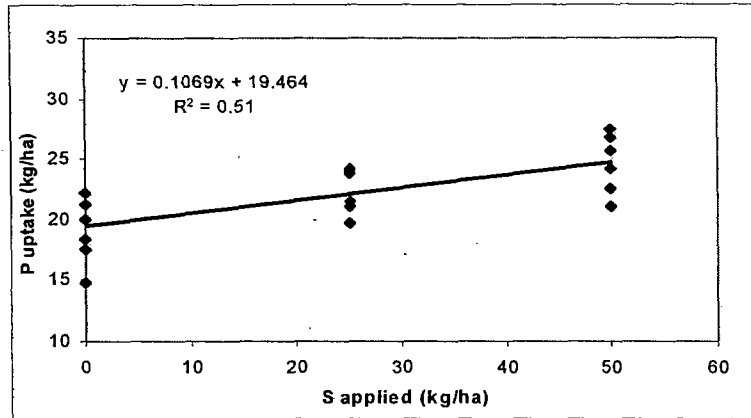
(2005)

Treatments	P uptake (mg/plant)													
	2005													
	25 DAS			50 DAS			75 DAS			At harvest				
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total	
Nitrogen sources														
PU	5.27	1.80	29.87	60.07	90.16	127.96	25.21	61.24	138.93	301.28	501.45			
CAN	5.23	1.96	31.55	57.98	101.39	139.43	27.22	64.17	148.30	313.30	525.77			
SEM +	0.06	0.02	0.31	0.38	1.02	1.64	0.32	0.85	1.84	0.32	12.19			
LSD (P=0.05)	NS	NS	0.93	NS	2.83	4.06	0.89	2.36	5.10	0.89	33.79			
Sulphur levels (kg/ha)														
0	4.81	1.55	27.30	43.25	82.53	116.41	21.81	51.45	114.76	278.72	444.91			
25	5.31	1.94	31.26	53.95	96.30	134.05	26.42	66.39	141.74	313.32	521.45			
50	5.64	2.16	33.58	79.87	108.49	150.62	30.40	70.33	174.34	329.81	574.48			
SEM +	0.08	0.02	0.43	0.79	1.25	2.01	0.39	1.04	3.18	0.39	17.24			
LSD (P=0.05)	0.22	0.08	1.21	2.21	3.46	5.50	1.09	2.89	8.84	1.09	47.79			
Boron levels (kg/ha)														
0	4.69	1.47	25.40	47.41	76.26	109.92	21.04	52.94	105.30	279.56	437.83			
0.75	5.28	1.90	30.82	57.50	96.84	132.71	26.35	59.35	154.66	305.06	519.09			
1.50	5.76	2.29	35.91	72.17	114.21	160.02	31.26	75.83	170.83	337.24	583.92			
SEM +	0.08	0.02	0.43	0.79	1.25	2.01	0.39	1.04	3.18	0.39	17.24			
LSD (P=0.05)	0.22	0.08	1.21	2.21	3.46	5.50	1.09	2.89	8.84	1.09	47.79			
Absolute control	2.05	0.59	17.40	23.69	37.81	61.48	10.96	16.63	64.62	228.47	309.72			
Rest	5.25	1.88	30.71	59.02	95.77	133.69	26.21	62.70	143.61	307.28	513.61			
SED +	0.09	0.07	1.21	6.06	9.91	4.94	0.98	6.89	12.22	0.98	29.86			
LSD (P=0.05)	0.18	0.14	2.44	12.24	20.01	9.97	1.97	13.91	24.68	1.97	60.31			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	P uptake (mg/plant)													
	2006													
	25 DAS			50 DAS			75 DAS			At harvest				
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total	
Nitrogen sources														
PU	5.12	1.50	28.84	53.83	83.63	114.51	22.70	53.55	117.42	299.81	471.11			
CAN	5.55	1.57	30.54	59.56	90.54	124.39	27.52	56.47	132.84	302.67	491.65			
SEM +	0.71	0.11	1.13	2.69	1.49	2.86	3.44	1.11	3.17	2.63	7.13			
LSD (P=0.05)	NS	NS	NS	NS	4.12	7.92	NS	NS	8.78	NS	NS			
Sulphur levels (kg/ha)														
0	4.46	1.16	26.54	42.61	73.89	98.49	18.71	45.20	102.28	283.66	430.81			
25	5.36	1.62	29.84	56.78	87.35	121.25	26.43	55.58	121.45	300.72	475.40			
50	6.17	1.81	32.69	70.69	99.78	138.61	30.21	66.22	151.67	319.36	536.95			
SEM +	0.71	0.14	1.50	4.79	8.14	7.12	3.49	1.64	6.06	9.97	11.16			
LSD (P=0.05)	1.96	0.42	4.17	13.28	22.57	19.72	9.69	4.06	16.81	27.64	30.93			
Boron levels (kg/ha)														
0	4.39	1.26	25.64	44.91	72.46	111.45	17.95	42.84	98.78	279.51	421.13			
0.75	5.46	1.47	30.89	55.09	84.17	115.53	25.16	57.80	126.56	296.54	480.90			
1.5	6.14	1.86	32.48	70.09	104.39	131.45	32.22	64.38	150.07	327.68	541.13			
SEM +	0.71	0.14	1.50	4.79	8.14	7.12	3.49	1.64	6.06	9.97	11.16			
LSD (P=0.05)	1.96	0.42	4.17	13.28	22.57	19.72	9.69	4.06	16.81	27.64	30.93			
Absolute control	2.63	0.97	17.84	27.39	42.97	59.86	12.79	19.87	73.46	212.97	312.81			
Rest	5.33	1.53	29.69	56.69	87.00	119.45	25.11	55.00	125.13	301.24	481.05			
SED +	0.86	0.20	2.79	4.55	6.89	15.60	4.39	4.94	14.10	13.67	23.69			
LSD (P=0.05)	1.73	0.40	5.15	9.19	13.91	31.51	8.86	9.97	28.48	27.61	47.85			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing



$$P_{\text{uptake}} = 13.13562 + 0.064431 \cdot S_{\text{applied}} + 2.119103 \cdot B_{\text{applied}}$$

$$R^2 = 0.82$$

Fig.13. P uptake in sunflower seed due to S and B levels

equally effective. An ample response was noticed even at the higher doses. All sources at all application rates were significantly superior than absolute control. The results were confirmed due to similar pattern followed by sunflower during the second year also.

At 50 DAS, stem became the main importer of P. It accumulated more P than leaves during both the years, all the treatments were superior than absolute control. N sources were not able to cause any significant difference in any of the seasons. Application of S enhanced the P uptake by stem and leaves at the subsequent doses, although the increase was more or less same with both the doses of S application @ 25 kg/ha and 50 kg/ha during both the years. A similar trend was seen also with B, where higher dose i.e. 1.5 kg B/ha proved to be more effective in enhancing the P uptake by the crop.

At harvest stage, maximum P uptake was noticed in the seed during both the years, which was not influenced due to any of the N source in 2006. Application of S and B significantly improved the P uptake by seed. For both the years, the S application @ 25 kg/ha gave better results as crop responded more sharply at this dose. A subsequent enhancement was seen at 50 kg S/ha as well, but the response was lower in 2005 and almost same in 2006. Similarly, B was a good choice and it helped to increase the P uptake by the crop and the response was more or less similar to both the doses. In stem more P uptake was noticed at harvest stage in both the years. N source had a significant effect in 2005 where CAN helped in significantly higher uptake of P than urea but the effect was non-significant in 2006. S enhanced P uptake at both doses with similar rates during both the seasons while the effect of B was also seen during both the years. Similar trend was recorded with root and leaf also, which was followed similarly during both the years of study.

Total P uptake in sunflower plants was increased with increasing doses of both S and B. Their individual relationship can be written as:

(A) Relationship with S doses:

$$Y = 0.1069 (x) + 19.464$$

$$R^2 = 0.51$$

Where, Y = Total P uptake (kg/ha)

x = Doses of S (kg/ha)

(B) Relationship with B doses:

$$Y = 3.2736 (x) + 19.669$$

$$R^2 = 0.57$$

Where, Y = Total P uptake (kg/ha)

X = Doses of B (kg/ha)

The combined multiple regression equation obtained was:

$$P \text{ uptake} = 13.13562 + 0.064431 S \text{ applied} + 2.119103 B \text{ applied.}$$

4.1.5.5 Potassium concentration

The results on K concentration in different plant parts (stem and leaves) were recorded at 25, 50, 75 DAS and at harvest stage. K concentration was recorded in all the plant parts and are presented in Table 28-29.

A careful perusal of data indicated higher values for K concentration in the first year were recorded as compared to the second year crop. Throughout the life span of sunflower the range of K concentration did not vary much. Different plant parts like leaf, stem and root showed higher concentration of K than seed. The concentration fluctuated according to the extent of fluctuation in dry matter accumulation by the plant parts at different crop growth stages.

At 25 DAS, application of various treatments registered significant influence on K concentration than absolute control. N application was effective in giving a thrust to the K concentration. Interestingly, CAN as an N source was effective during both the years in enhancing the K concentration of both leaves and stem. The concentration in leaves was almost double with that of the stem. Various levels of S also significantly increased the K concentration. K concentration was the highest in leaf and stem when S was applied @ 50 kg/ha. B was equally influential to raise the K concentration in both leaf and stem of sunflower. A similar trend was recorded during both the years of the study.

Treatments	K concentration (%)											
	2005											
	25 DAS			50 DAS			75 DAS			At harvest		
	Stem	Leaf	Seed	Stem	Leaf	Seed	Stem	Leaf	Seed	Stem	Leaf	Seed
Nitrogen sources												
PU	0.63	1.65	1.07	1.91	1.60	2.55	1.22	2.17	2.53	2.19		
CAN	0.64	1.76	1.28	2.14	1.88	2.70	1.28	2.15	2.58	2.25		
SEm ±	0.007	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02
LSD (P=0.05)	0.021	0.04	0.03	0.06	0.04	0.06	0.03	NS	NS	NS	NS	NS
Sulphur levels (kg/ha)												
0	0.56	1.55	0.95	1.83	1.60	2.46	1.23	1.92	2.49	2.14		
25	0.64	1.73	1.11	2.08	1.79	2.53	1.22	2.15	2.57	2.23		
50	0.70	1.83	1.47	2.16	1.85	2.57	1.31	2.40	2.61	2.29		
SEm ±	0.009	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.03	0.02	0.03	0.02
LSD (P=0.05)	0.026	0.06	0.05	0.07	0.05	0.08	0.04	0.07	0.09	0.06	0.09	0.06
Boron levels (kg/ha)												
0	0.50	1.52	0.97	1.95	1.59	2.41	1.14	2.04	2.47	2.09		
0.75	0.66	1.69	1.18	1.95	1.80	2.50	1.24	2.14	2.55	2.25		
1.50	0.73	1.90	1.36	2.17	1.83	2.66	1.37	2.29	2.65	2.31		
SEm ±	0.009	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.03	0.02	0.03	0.02
LSD (P=0.05)	0.026	0.06	0.05	0.07	0.05	0.08	0.04	0.07	0.09	0.06	0.09	0.06
Absolute control	0.46	1.07	0.50	1.42	1.10	2.01	0.93	1.67	2.35	1.87		
Rest	0.63	1.70	1.17	2.02	1.74	2.52	1.25	2.15	2.55	2.21		
SEd +	0.02	0.05	0.01	0.06	0.04	0.07	0.03	0.06	0.08	0.07	0.08	0.07
LSD (P=0.05)	0.04	0.10	0.02	0.12	0.08	0.14	0.06	0.12	0.16	0.12	0.16	0.14

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

various crop growth stages (2006)

Treatments	K concentration (%)														
	2006														
	25 DAS			50 DAS			75 DAS			At harvest					
	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Root	Stem	Leaf	Seed	
Nitrogen sources															
PU	0.54	1.24	1.12	1.84	1.48	2.40	1.20	2.20	2.39	2.18					
CAN	0.68	1.46	1.25	2.11	1.77	2.67	1.26	2.33	2.54	2.27					
SEM +	0.006	0.03	0.01	0.02	0.01	0.08	0.01	0.04	0.03	0.02					
LSD (P=0.05)	0.018	0.09	0.03	0.06	0.03	0.24	0.03	0.11	0.10	0.05					
Sulphur levels (kg/ha)															
0	0.52	1.12	0.94	1.69	1.44	2.25	1.17	2.02	2.12	2.06					
25	0.64	1.37	1.21	2.00	1.69	2.59	1.22	2.17	2.51	2.23					
50	0.68	1.57	1.52	2.22	1.73	2.76	1.32	2.59	2.75	2.38					
SEM +	0.007	0.02	0.02	0.02	0.04	0.03	0.01	0.03	0.05	0.04					
LSD (P=0.05)	0.021	0.06	0.06	0.05	0.11	0.08	0.04	0.09	0.15	0.11					
Boron levels (kg/ha)															
0	0.48	1.22	1.03	1.78	1.33	2.26	1.04	1.98	2.24	1.97					
0.75	0.64	1.34	1.22	1.97	1.69	2.59	1.26	2.31	2.49	2.28					
1.50	0.72	1.51	1.42	2.17	1.84	2.75	1.39	2.50	2.65	2.45					
SEM +	0.007	0.02	0.02	0.02	0.04	0.03	0.01	0.03	0.05	0.04					
LSD (P=0.05)	0.021	0.06	0.06	0.05	0.11	0.08	0.04	0.09	0.15	0.11					
Absolute control	0.40	0.99	0.60	1.36	1.09	1.98	0.94	1.49	2.11	1.49					
Rest	0.61	1.35	1.22	1.97	1.62	2.53	1.23	2.26	2.46	2.22					
SED +	0.02	0.05	0.03	0.07	0.04	0.07	0.05	0.11	0.09	0.07					
LSD (P=0.05)	0.04	0.10	0.06	0.14	0.08	0.14	0.10	0.22	0.18	0.14					

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

A similar trend in K concentration in leaves and stem was followed at 50 DAS. The K concentration was higher in leaves than stem but ratio of K concentration in leaf:stem declined than 25 DAS. Here also, CAN proved as a better source in enhancing the K concentration significantly in stem and leaves during both the years. S doses were able to increase the K concentration in leaves and stem significantly at both 25 and 50 kg S/ha application during both the years of the experimentation. The two levels of B i.e. 0.75 and 1.5 kg/ha significantly enhanced the K concentration in leaves and stem of sunflower. Surprisingly, the rate of increase was higher at first dose than the second dose during both the years. As per the usual trend, absolute control recorded significantly lower values of K concentration of stem or leaves during any of the years.

At 75 DAS, the ratio of K concentration in leaf and stem declined further. CAN again proved as an effective source for enhancing K concentration in both leaves and stem in 2005 and 2006 as well. In 2005, S was able to increase the K concentration at both doses but the K concentration due to S application @ 25 kg/ha remained statistically at par with S @ 50 kg/ha in stem. In leaves, there was significant increase in the concentration of K up to application of 50 kg S/ha also. In 2006, response of the crop due to S was interesting as even up to 50 kg S/ha, the K concentration enhanced linearly. The response of crop in enhancing K concentration due to application of different levels of B can be predicted from the data. It revealed that B had a positive impact to enhance the K concentration in leaves and stem. During both the years of the study, B application enhanced K concentration at a higher rate till 0.75 kg/ha and then the decline in the rate of increase was observed. But all the treatments were significantly superior over absolute control.

At harvest stage, vegetative parts accumulated higher K concentration than seed. Leaf experienced the highest K concentration, while roots had the lowest. At harvest stage also, K concentration was significantly higher when N application was done with CAN than urea. But in 2005, the increase was non-significant. In roots, the higher K concentration was noticed due to S application, the response was positive even up to 50 kg S/ha, but the rate of increase declined beyond 25 kg S/ha. B application was significant during both the years of the study. In stem also, a subsequent increase with S and B doses were noticed during 2005 and 2006 as well. In

leaves 2-5% enhancement in K concentration was noticed due to S application in both the years. B was also able to cause an ample effect in K concentration of leaves. B application @ 1.5 kg/ha could enhance the K concentration up to 10% during both the years of the study. Seed was the final component at harvest to accumulate K. N source i.e. urea and CAN both enhanced the K concentration in seed but increase was significantly higher with CAN and that also only during the second year. S application was able to increase the K concentration significantly at both the doses during the second year but the increase was more due to B application. B application @ 1.5 kg/ha brought maximum increase in K concentration in seed up to 15%. The overall study of the data reveals that all fertilizer treatments were significantly superior than absolute control during both the years of the study.

4.1.5.6 Potassium uptake

K uptake by stem and leaves (at 25, 50, 75 DAS) and at harvest in root, stem, leaf and seed is presented in Table 30-31 and Fig. 14. The uptake of K by plant depended on the trend of dry matter accumulation and its concentration. Lower uptake was recorded in early stages and it increased with advancement in growth stage of the crop. During both the years at 25 DAS the uptake was higher in leaves but with the advanced stages, the uptake was higher by stem.

At 25 DAS, K uptake was higher by leaf and stem in 2005 than in 2006. Initially the K uptake was about 10 times higher in leaf than in the stem but it was reversed as the plants grew older. N sources failed to cause any significant difference in K uptake by the crop except in 2006 when CAN produced significantly higher K uptake by stem. S had a pronounced effect on K uptake by leaf and stem of sunflower during both the years. The uptake of K increased even at 50 kg S/ha while the ratio of K uptake between leaf and stem was maintained at both the doses. Application of B had a similar effect in both the years. The K uptake was significantly influenced by B application but the response was higher at 0.75 kg B/ha. At 1.5 kg B/ha also, the K uptake was more but the change was less. Here, all the fertilizer treatments were significantly superior than absolute control.

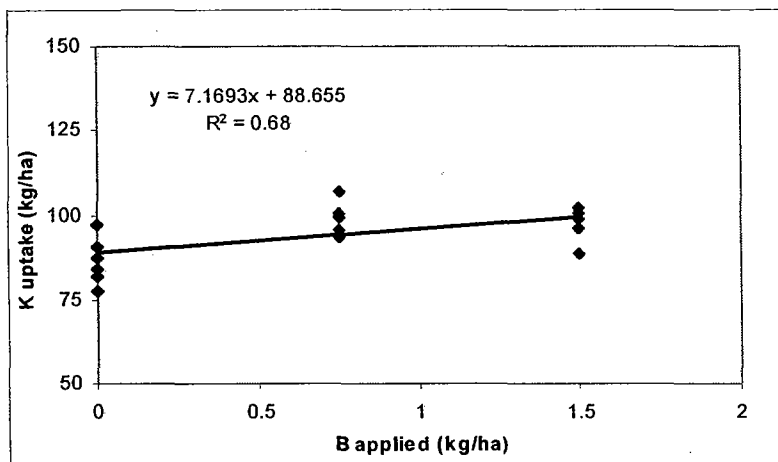
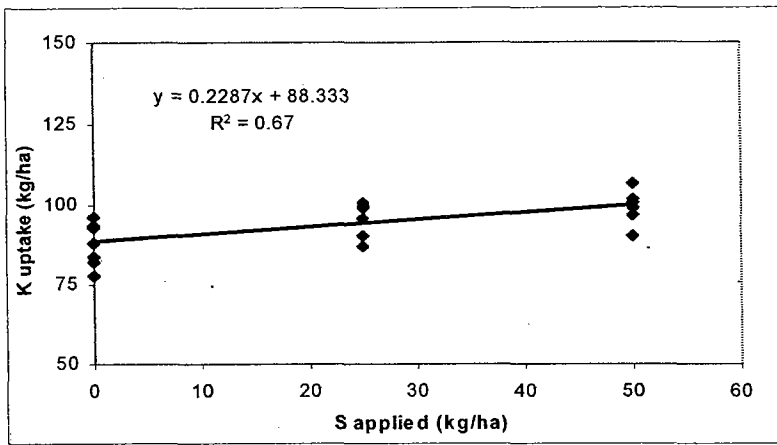
At 50 DAS, stem accumulated more K. The values were higher in the first year than the second one. During 2005, between two N sources, both urea and CAN

Treatments	K uptake (mg/plant)												
	2005												
	25 DAS			50 DAS			75 DAS			At harvest			
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total
Nitrogen sources													
PU	22.40	2.74	173.77	181.82	798.71	685.21	191.85	665.63	1069.82	769.12	2504.57		
CAN	23.11	3.12	192.53	201.04	833.01	756.87	202.31	626.30	1062.19	810.95	2499.44		
SEm +	1.31	2.04	9.43	10.60	10.70	12.70	2.32	10.06	13.52	25.28	22.69		
LSD (P=0.05)	NS	NS	NS	NS	NS	35.17	NS	NS	NS	NS	NS		NS
Sulphur levels (kg/ha)													
0	20.43	2.05	161.45	130.29	751.40	616.31	184.52	575.79	895.81	680.89	2154.49		
25	23.29	2.75	185.83	171.16	830.86	680.67	188.35	665.91	1060.17	810.84	2538.92		
50	24.54	4.01	202.15	272.85	865.33	866.15	218.34	696.20	1242.04	884.53	2824.77		
SEm +	1.38	0.05	10.98	13.18	13.10	15.88	2.84	11.09	16.56	38.97	31.88		
LSD (P=0.05)	3.82	0.15	30.41	36.50	36.33	43.93	7.89	30.76	45.92	85.85	88.30		
Boron levels (kg/ha)													
0	18.76	1.89	168.78	137.77	691.94	645.58	168.76	577.73	895.60	678.42	2218.41		
0.75	23.10	2.79	177.29	194.38	819.27	690.43	192.51	637.24	1065.91	822.49	2392.30		
1.5	26.40	4.12	203.37	242.14	936.38	827.12	229.96	722.92	1236.51	875.34	2901.43		
SEm +	1.38	0.05	10.98	13.18	13.10	15.88	2.84	11.09	16.56	38.97	31.88		
LSD (P=0.05)	3.82	0.15	30.41	36.50	36.33	43.93	7.89	30.76	45.92	85.85	88.30		
Absolute control													
Absolute control	8.77	0.50	112.32	45.55	447.02	338.14	127.41	355.32	601.37	486.51	1443.20		
Rest	22.75	2.93	183.14	191.43	815.86	721.04	197.07	645.96	1066.0	792.08	2504.04		
SEd +	1.94	0.06	17.31	17.81	32.10	20.57	4.93	27.92	28.69	53.64	75.86		
LSD (P=0.05)	3.91	0.12	34.96	35.77	34.12	41.55	9.95	56.39	57.95	108.35	153.23		

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	K uptake (mg/plant)												
	2006												
	25 DAS			50 DAS			75 DAS			At harvest			
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total
Nitrogen sources													
PU	16.19	1.40	159.26	170.54	729.68	595.19	171.33	591.52	983.57	758.19	2333.28		
CAN	18.07	1.84	184.54	198.84	751.13	625.11	190.13	630.72	1025.28	770.62	2426.62		
SEM +	1.23	0.03	5.84	4.61	8.34	12.61	7.40	14.76	10.76	11.73	17.24		
LSD (P=0.05)	NS	0.09	16.17	12.76	NS	NS	NS	NS	29.80	NS	47.75		
Sulphur levels (kg/ha)													
0	13.51	1.07	137.3	120.94	611.54	512.67	131.31	464.96	812.43	668.57	1945.96		
25	17.61	1.63	168.54	171.06	752.91	622.52	291.71	606.21	963.37	765.45	2335.03		
50	20.28	2.19	209.88	262.07	856.75	695.27	219.23	762.21	1237.63	859.18	2859.09		
SEM +	1.42	0.07	6.43	5.87	14.49	13.49	8.70	14.10	11.16	13.67	19.97		
LSD (P=0.05)	3.95	0.20	17.82	16.27	41.27	37.36	24.10	39.10	30.97	37.91	55.31		
Boron levels (kg/ha)													
0	13.72	1.09	140.2	131.06	611.54	465.89	139.61	511.65	810.42	648.14	1970.19		
0.75	17.52	1.60	182.29	174.93	752.91	623.97	175.41	607.25	994.52	780.21	2381.98		
1.5	20.17	2.19	193.22	248.08	856.75	740.59	227.24	714.46	1208.46	864.85	2787.77		
SEM +	1.42	0.07	6.43	5.87	14.49	13.49	8.70	14.10	11.16	13.67	19.97		
LSD (P=0.05)	3.95	0.20	17.82	16.27	41.27	37.36	24.10	39.10	30.97	37.91	55.31		
Absolute control	10.75	1.09	99.83	59.87	465.71	326.72	12.71	370.41	620.72	442.71	1433.84		
Rest	17.13	1.62	171.91	184.69	740.40	610.15	180.73	611.12	1004.47	764.4	2379.99		
SED +	2.46	0.32	10.17	14.38	24.49	16.06	10.21	19.34	23.69	33.50	24.43		
LSD (P=0.05)	4.96	0.64	20.54	29.04	48.88	32.44	20.42	39.06	47.85	67.67	49.34		

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing



$$K_{\text{uptake}} = 83.95574 + 0.214063 \cdot S_{\text{applied}} + 6.64722 \cdot B_{\text{applied}}$$

$$R^2 = 0.73$$

Fig.14. K uptake in sunflower seed due to S and B levels

proved to be significantly at par in enhancing the K uptake by the crop. While the difference was significant during 2006. In 2005, a sharp increase in the uptake of K was experienced on application of S @ 50 kg/ha from 25 kg/ha. In 2006, a similar trend was noticed. In 2005, the application of B enhanced the K uptake in both leaf and stem. The uptake was enhanced more quickly by the application of higher dose. A very positive response was experienced at 1.5 kg B/ha in 2006 also. All the treatments separately were better than the control which resulted in the lowest K uptake during both the years of the study.

At 75 DAS, about 4 times increase in the K uptake by leaf and stem was experienced than at 50 DAS. In 2005, the difference due to N sources were recorded in stem with CAN as a better source while it was at par with urea in 2006. Application of S improved the K uptake by both stem and leaf even at 50 kg S/ha. Likewise B was also more responsive at the higher dose of 1.5 kg B/ha where in K uptake was maximum. The similar trend was seen during the second year also although the values were numerically lower in 2006.

At harvest stage, the highest K uptake was observed in stem during both the years. In 2005, the K uptake by roots was not influenced significantly by the N sources, where CAN was found to be statistically at par while for 2006 also, both the sources were equally effective when S was applied, in 2005 a sharp response was seen at the second dose i.e. 50 kg S/ha, while in 2006 a quick response was recorded with 25 kg S/ha than the higher dose. B application followed more or less similar trend. In 2005, clear response was seen at higher doses, while in 2006, even 0.75 kg B/ha proved to be far better.

The K uptake by leaf was more than that of root. In 2005, it was not significantly influenced by N sources and CAN remained statistically at par with urea and during 2006 also, it was non-significant. In 2005, S and B gave almost equal results at both doses. Both the doses were found to be significant during 2005 and 2006 as well. Stem was the major part which accumulated maximum K during both the years. It followed the previous pattern of leaf and stem. N sources were non-significant in 2005 and 2006 and both the N sources remained statistically at par with each other.

S and B levels were significant even up to the higher doses during both the years while all were certainly better than absolute control.

The K uptake by seed was comparatively lower than the vegetative parts. In 2005, the difference due to urea and CAN as a N source was found to be non-significant, and also during 2006. Higher K uptake was noticed by sunflower seed with S application @ 50 kg/ha, although S @ 25 kg/ha was also significant. A similar trend was seen for B. In both 2005 and 2006, a higher change was noticed at the first dose of 0.75 kg B/ha than the higher dose of 1.5 kg B/ha. All the treatments were not in comparison with control which produced the lowest K uptake in both the years of the study.

Total K uptake is also related to application of S and B. Both the nutrients had a positive effect on K uptake which can be quantified as:

(A) Relationship with S:

$$Y = 0.2287 (x) + 88.33$$

$$R^2 = 0.67$$

Where, Y = Total K uptake (kg/ha)

x = Doses of S (kg/ha)

(B) Relationship with B:

$$Y = 7.1688 (x) + 88.65$$

$$R^2 = 0.68$$

Where, Y = Total K uptake (kg/ha)

R² = Doses of B (kg/ha)

Combining both the equations, the multiple regression equation could be written as:

$$\text{K uptake} = 83.95574 + 0.214063 \text{ S applied} + 6.64722 \text{ B applied.}$$

4.1.5.7 S concentration

The concentration of S in leaf and stem (at 25, 50, 75 DAS) and in root, shoot, leaf and seed was estimated at harvest which is shown in Table 32, 33 and Fig. 15 and

crop growth stages (2005)

Treatments	S concentration (%)												
	2005												
	25 DAS			50 DAS			75 DAS			At harvest			
	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Seed
Nitrogen sources													
PU	0.33	0.35	0.28	0.32	0.23	0.24	0.23	0.24	0.18	0.15	0.14	0.15	0.23
CAN	0.33	0.35	0.29	0.33	0.24	0.25	0.24	0.25	0.19	0.24	0.15	0.24	0.24
SEM +	0.004	0.004	0.003	0.003	0.002	0.003	0.002	0.003	0.002	0.002	0.001	0.002	0.002
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sulphur levels (kg/ha)													
0	0.31	0.33	0.27	0.31	0.23	0.24	0.23	0.24	0.14	0.17	0.13	0.17	0.21
25	0.34	0.35	0.28	0.32	0.23	0.25	0.23	0.25	0.16	0.19	0.14	0.19	0.25
50	0.35	0.37	0.30	0.34	0.25	0.25	0.25	0.25	0.24	0.24	0.15	0.24	0.28
SEM +	0.005	0.01	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.004	0.001	0.002	0.003
LSD (P=0.05)	0.014	0.03	0.011	0.012	0.009	0.010	0.009	0.010	0.007	0.011	0.005	0.007	0.009
Boron levels (kg/ha)													
0	0.32	0.33	0.27	0.31	0.22	0.23	0.22	0.23	0.17	0.19	0.13	0.19	0.19
0.75	0.33	0.35	0.29	0.32	0.24	0.25	0.24	0.25	0.19	0.20	0.14	0.20	0.25
1.50	0.36	0.37	0.30	0.34	0.25	0.26	0.25	0.26	0.20	0.22	0.16	0.22	0.30
SEM +	0.005	0.01	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.004	0.001	0.002	0.003
LSD (P=0.05)	0.014	0.03	0.011	0.012	0.009	0.010	0.009	0.010	0.007	0.011	0.005	0.007	0.009
Absolute control	0.28	0.30	0.24	0.29	0.19	0.20	0.19	0.20	0.14	0.14	0.10	0.14	0.16
Rest	0.33	0.35	0.28	0.32	0.23	0.24	0.23	0.24	0.18	0.20	0.14	0.20	0.24
SED +	0.006	0.03	0.003	0.01	0.01	0.06	0.01	0.06	0.007	0.005	0.04	0.007	0.008
LSD (P=0.05)	0.012	0.06	0.006	0.02	0.02	0.12	0.02	0.12	0.014	0.010	0.08	0.014	0.016

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

various crop growth stages (2006)

Treatments	S concentration (%)													
	25 DAS			50 DAS			75 DAS			At harvest				
	Stem	Leaf		Stem	Leaf		Stem	Leaf		Root	Stem	Leaf	Seed	
Nitrogen sources														
PU	0.31	0.32		0.27	0.30		0.25	0.26		0.13	0.19	0.20	0.26	
CAN	0.32	0.33		0.28	0.31		0.26	0.27		0.14	0.20	0.22	0.27	
SEm +	0.004	0.003		0.004	0.005		0.002	0.003		0.004	0.005	0.006	0.005	
LSD (P=0.05)	NS	NS		NS	NS		NS	NS		NS	NS	NS	NS	
Sulphur levels (kg/ha)														
0	0.30	0.30		0.26	0.28		0.22	0.24		0.11	0.16	0.18	0.24	
25	0.32	0.34		0.29	0.31		0.25	0.28		0.14	0.20	0.21	0.27	
50	0.34	0.37		0.31	0.34		0.29	0.31		0.18	0.24	0.26	0.30	
SEm +	0.004	0.01		0.003	0.004		0.003	0.004		0.002	0.004	0.003	0.004	
LSD (P=0.05)	0.012	0.03		0.009	0.012		0.009	0.012		0.006	0.012	0.011	0.012	
Boron levels (kg/ha)														
0	0.31	0.31		0.22	0.30		0.21	0.24		0.11	0.17	0.18	0.23	
0.75	0.32	0.33		0.29	0.31		0.25	0.27		0.14	0.20	0.22	0.27	
1.50	0.35	0.37		0.34	0.34		0.29	0.30		0.17	0.24	0.25	0.32	
SEm +	0.004	0.01		0.003	0.004		0.003	0.004		0.002	0.004	0.003	0.004	
LSD (P=0.05)	0.012	0.03		0.009	0.012		0.009	0.012		0.006	0.012	0.011	0.012	
Absolute control														
Absolute control	0.24	0.29		0.21	0.24		0.19	0.22		0.11	0.14	0.17	0.18	
Rest	0.32	0.33		0.28	0.31		0.25	0.27		0.14	0.20	0.21	0.27	
SEd +	0.007	0.05		0.05	0.006		0.002	0.06		0.004	0.008	0.006	0.009	
LSD (P=0.05)	0.014	0.10		0.10	0.014		0.004	0.14		0.008	0.016	0.012	0.018	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

16. A careful observation of data revealed that S concentration reduces with advancement in growth stage from 25 DAS to harvest. The values of S concentration were higher during the first year than the second year.

At 25 DAS, slightly higher values of S concentration were observed during both the years. Both the sources of N i.e. urea and CAN remained statistically at par with each other. S application, of course brought a significant change in the S concentration of both stem and leaf. At 25 DAS, the change was lesser. Although both the doses were effective, a more sharp change was noticed at 25 kg S/ha which declined at 50 kg S/ha. Both the years followed the similar pattern. B application also enhanced the S concentration up to a certain limit although not as high as with S application. At both the doses of B, a slight increase in the S concentration of leaf and stem was noticed during both 2005 and 2006 years of experimentation. The similar pattern was observed during 50 and 75 DAS also. The concentration of S in leaf and stem diluted up to 43% and 40% respectively for leaf and stem. N sources remained ineffective during 2005 but they failed to cause impact in 2006 also. S and B were effective in more or less similar pattern during both the years of the experimentation.

At harvest stage, seed accumulated maximum S concentration during both the years, followed by leaf, stem and least in roots. In 2005, there was a significant difference caused by N sources in S concentration at different parts of sunflower plant but was non-significant in 2006. S was important to enhance the S concentration of roots. Almost equal response by the crop due to S was observed at 25 and 50 kg S/ha. B was also effective but less than S for enhancement in S concentration in roots. Stem and leaves followed the same pattern during both the years of the experimentation. S application enhanced the S concentration of seed during both the years. The gain in S concentration due to levels of S was equal at both the doses. Interestingly, B application was found to be very effective for accumulation of S in the seeds. The higher doses of B helped to raise the S concentration of seed even higher than the S application itself. The results were confirmed by the findings of both the years of the study.

4.1.5.8 S uptake

S uptake by stem and leaf (at 25, 50, 75 DAS) and root, stem, leaf and seed at harvest stage is shown in Table 34, 35 and Fig. 15, 16 and 19. A careful perusal of the data revealed that S uptake followed the same pattern to that of S concentration, as it depends upon the S concentration and dry matter accumulation at different crop growth stages. All the values for S uptake were higher during the first year than the second year of the study. There was a progressive increase in the S uptake of stem and leaf till 75 DAS and declined thereafter. S uptake by leaves was higher only at 25 DAS and beyond that stage, stem recorded the higher uptake than leaves till harvest stage. In 2005, difference in S uptake in leaves due to N sources at 25 and 50 DAS were non-significant. While difference in stem was significant, whereas in 2006 all the differences at various crop growth stages were non-significant. S and B application had a steady significant effect on S concentration of leaf and stem till 75 DAS and all treatments were significantly superior than absolute control.

At harvest stage, seed accumulated maximum S during both the years, followed by stem, leaf and minimum in roots. N sources had a significant effect on the S uptake by stem and leaf in 2005 while just reverse of that, it was non-significant in all the plant parts for the year 2006. S application improved S uptake by the crop in all different plant parts like root, stem, leaves and seed but the response was higher at the first dose of S application @ 25 kg/ha than that the higher dose i.e. @ 50 kg S/ha. A similar trend was seen for B during both the years of the study. All the fertilizer treatments had significantly higher uptake than absolute control during 2005 and 2006 as well.

S uptake in seed was higher with increasing S uptake. S levels in stover was also relative to S concentration in seed as:

$$Y = 2.2361 (x) + 4.6547$$

$$R^2 = 0.72$$

Where, Y = S uptake in seed (kg/ha)

x = S uptake by stover (kg/ha)

Treatments	S uptake (mg/plant)											
	2005											
	25 DAS			50 DAS			75 DAS			At harvest		
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total	
Nitrogen sources												
PU	4.54	1.40	25.35	47.60	71.92	99.11	21.95	53.25	90.83	95.69	239.77	
CAN	4.60	1.59	25.78	51.19	79.15	100.68	25.04	64.04	95.05	99.82	258.91	
SEM +	0.06	0.02	0.32	0.62	1.01	0.62	2.31	0.80	1.23	3.08	5.33	
LSD (P=0.05)	NS	0.05	NS	1.71	2.82	NS	NS	2.33	3.42	NS	NS	
Sulphur levels (kg/ha)												
0	4.27	1.37	23.86	43.25	69.33	90.25	19.95	47.11	78.49	82.56	208.16	
25	4.62	1.50	25.23	47.05	77.91	99.99	22.14	57.58	85.47	98.97	242.02	
50	4.82	1.62	27.61	57.89	79.37	109.45	28.40	71.27	114.86	111.72	297.85	
SEM +	0.07	0.02	0.39	0.76	1.24	1.62	3.38	0.98	1.51	3.77	6.53	
LSD (P=0.05)	0.20	0.07	1.09	2.11	3.46	4.51	9.36	2.73	4.19	10.45	18.11	
Boron levels (kg/ha)												
0	3.93	1.21	23.08	35.65	63.68	86.05	19.46	50.56	78.66	83.73	211.95	
0.75	4.45	1.45	25.80	52.17	78.12	101.12	23.96	60.78	93.62	100.65	254.05	
1.5	5.33	1.82	27.85	60.37	84.80	112.52	27.07	64.63	109.53	108.87	282.03	
SEM +	0.07	0.02	0.39	0.76	1.24	1.62	3.38	0.98	1.51	3.77	6.53	
LSD (P=0.05)	0.20	0.07	1.09	2.11	3.46	4.51	9.36	2.73	4.19	10.45	18.11	
Absolute control	2.26	0.58	18.67	26.15	41.58	61.79	13.70	22.79	48.97	54.71	126.47	
Rest	4.57	1.49	25.56	49.39	75.53	99.89	23.49	58.65	92.94	97.75	249.34	
SED +	0.12	0.06	0.99	1.86	2.16	3.99	4.93	2.41	3.70	9.24	9.49	
LSD (P=0.05)	0.24	0.12	1.99	3.75	4.36	8.05	9.95	4.84	7.47	18.66	19.16	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	S uptake (mg/plant)													
	2006													
	25 DAS			50 DAS			75 DAS			At harvest				
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total	
Nitrogen sources														
PU	4.34	1.07	23.77	40.03	83.68	81.86	23.14	53.37	99.09	91.73	244.19			
CAN	4.47	1.16	27.81	45.97	90.89	98.39	25.78	58.45	105.12	94.84	258.31			
SEm +	0.32	0.04	1.42	3.62	2.81	3.49	1.07	3.06	1.82	1.11	5.18			
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			NS
Sulphur levels (kg/ha)														
0	3.74	0.83	20.10	32.95	71.25	71.50	18.34	42.67	93.06	79.54	215.24			
25	4.43	1.16	35.19	41.34	85.35	88.37	24.47	54.49	100.20	94.63	249.29			
50	5.05	1.34	32.08	54.73	105.27	110.49	30.59	70.62	113.05	105.72	289.36			
SEm +	0.43	0.05	2.01	4.94	3.77	4.94	2.01	3.49	2.85	8.14	6.43			
LSD (P=0.05)	1.19	0.15	5.59	13.70	10.45	13.70	5.59	9.69	7.91	22.57	17.82			
Boron levels (kg/ha)														
0	3.74	0.94	22.64	34.00	73.71	72.94	18.41	44.51	78.34	80.29	213.14			
0.75	4.26	1.091	25.14	41.30	84.53	87.26	23.54	54.69	99.49	93.43	247.61			
1.5	5.21	1.30	29.55	53.72	103.59	110.15	31.43	68.53	128.47	106.12	293.12			
SEm +	0.43	0.05	2.01	4.94	3.77	4.94	2.01	3.49	2.85	8.14	6.43			
LSD (P=0.05)	1.19	0.15	5.59	13.70	10.45	13.70	5.59	9.69	7.91	22.57	17.82			
Absolute control	2.24	0.76	17.29	20.53	50.79	59.53	14.24	26.55	62.27	57.63	146.45			
Rest	4.40	1.11	25.79	43.00	87.29	90.12	24.46	55.91	102.10	93.29	251.30			
SEd +	0.71	0.06	2.98	5.17	5.33	9.24	2.85	3.49	25.82	9.97	14.10			
LSD (P=0.05)	1.43	0.12	6.01	10.44	10.77	18.66	5.75	7.04	52.15	20.13	28.48			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

2005

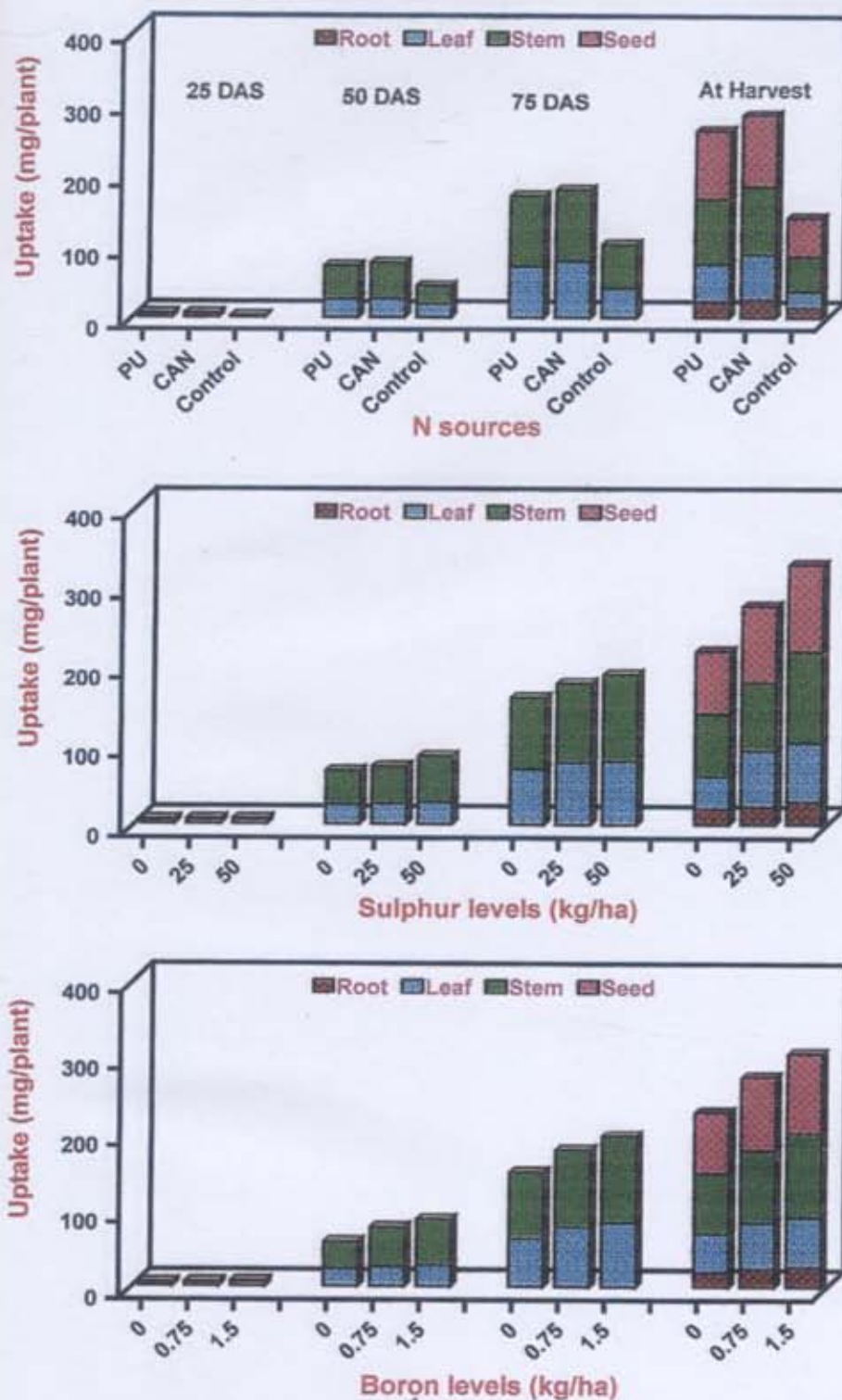


Fig. 15. Sulphur uptake per plant by sunflower as influenced by nitrogen sources, sulphur and boron levels (2005)

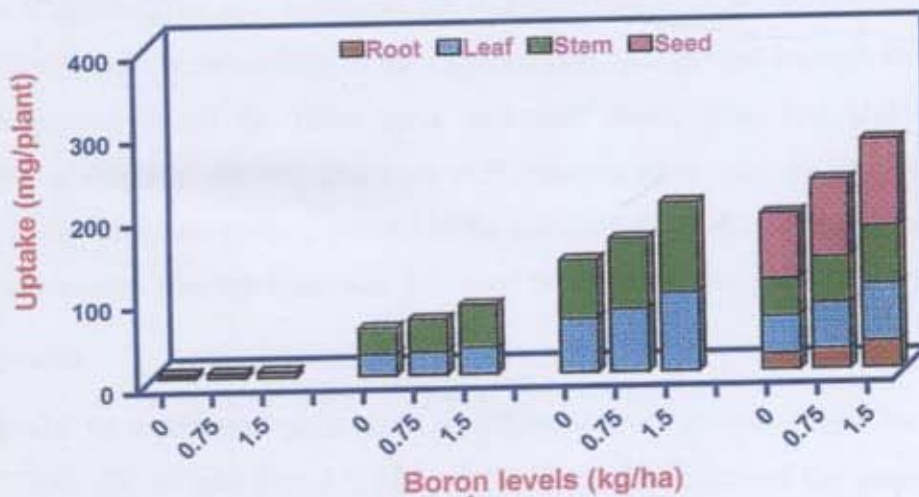
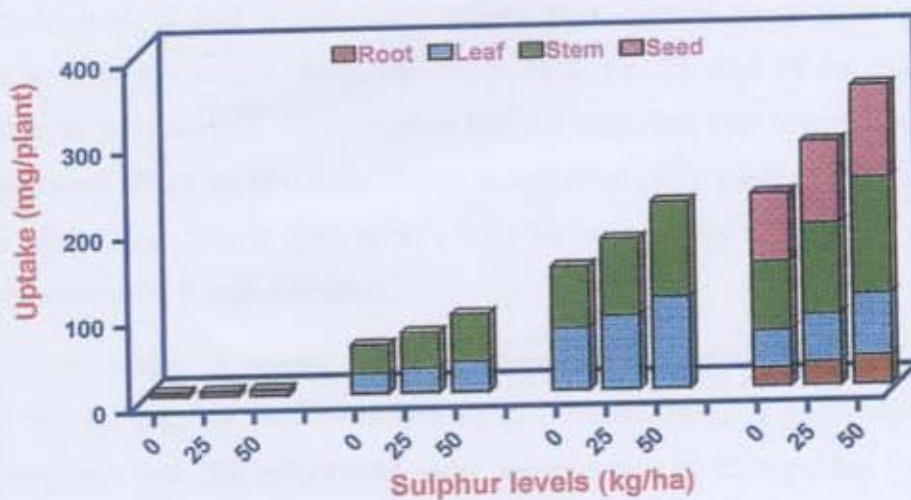
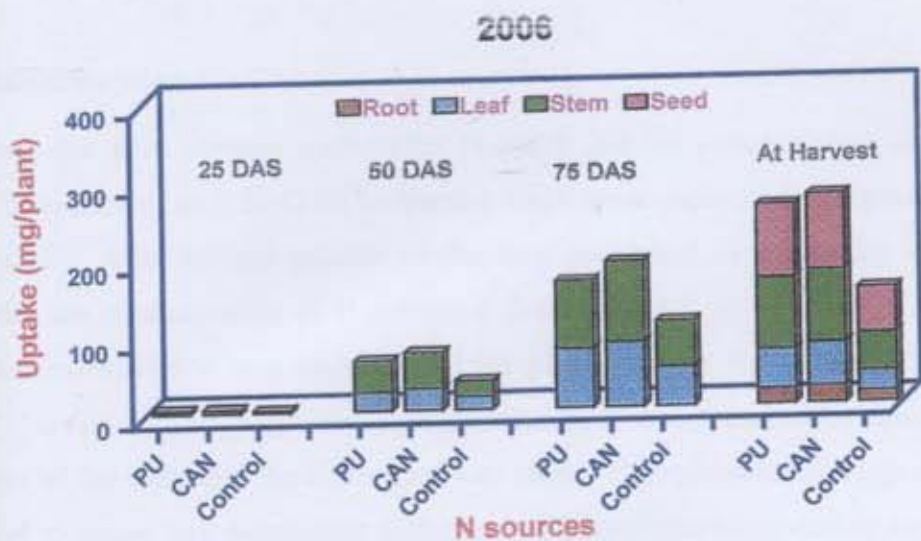


Fig. 16. Sulphur uptake per plant by sunflower as influenced by nitrogen sources, sulphur and boron levels (2006)

4.1.5.9 B concentration

B was the third element added after N and S and the concentration in various plant parts from 25, 50, and 75 DAS to harvest stage were estimated and presented in Table 36 and 37. After critical perusal of the data presented in the tables it can be concluded that the concentration of B enhanced from 25 DAS up to 75 DAS and then declined. The concentration was higher in all the plant parts in 2006 than in 2005. At 25, 50, 75 DAS and harvest stage, the concentration of B was found to be almost same in leaves than in the stem and the difference was slight. N application through different sources failed to cause any significant difference in B concentration during any of the year of the field trial. S had a significant effect over control in enhancing the B concentration at different stages. Both the doses of S i.e. 25 and 50 kg S/ha were equally effective in increasing B concentration but the influence was lower than that of B. B had a profound effect on B concentration in different plant parts at different crop growth stages of the crop. The B dose up to 1.5 kg/ha was equally effective in creating a reasonable increment in B concentration.

At harvest stage, N source failed to cause any significant difference in B concentration in any part of the sunflower crop. Results from S application were encouraging but here too, the effect was more pronounced at 25 kg S/ha. Although application of S @ 50 kg/ha also enhanced the B concentration of all the plant parts but the response was lower. B, according to the expectations, was potent enough to cause a significant difference in all the plant parts including stem, root, leaf and seed at different stages of the crop growth. The highest B concentration was observed with 1.5 kg B/ha. Here also absolute control proved to be a total failure as compared to any of the fertilizer treatments. Similar trend was followed during both the years of the study.

4.1.5.10 B uptake

B uptake by sunflower plant parts at different crop growth stages have been presented in Table 38, 39 and Fig. 17, 18 and 19. B uptake followed the pattern of B concentration in both the years of the study. N application through different sources could not make any difference in any of the year. All the values for B uptake were higher during the first year of the experimentation. There was a progressive increase in B uptake by different plant parts like stem and leaves till 75 DAS and then declined

Treatments	B concentration (mg/kg DM)												
	2005												
	25 DAS			50 DAS			75 DAS			At harvest			
	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Seed
Nitrogen sources													
PU	29.20	27.35	32.30	30.99	41.38	32.56	22.62	27.88	37.31	39.89			
CAN	29.07	27.21	32.55	31.04	41.42	32.51	22.73	27.84	37.35	39.82			
SEm +	0.17	0.16	0.14	0.17	0.29	0.17	0.10	0.14	0.20	0.14			
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			NS
Sulphur levels (kg/ha)													
0	28.01	26.09	31.35	30.01	40.39	31.30	21.69	27.21	36.38	39.21			
25	29.23	27.80	32.22	31.13	41.51	32.47	22.78	27.76	37.21	40.08			
50	30.17	27.97	33.68	31.90	42.32	33.84	23.54	28.62	38.41	40.26			
SEm +	0.21	0.20	0.20	0.21	0.36	0.22	0.12	0.17	0.24	0.17			
LSD (P=0.05)	0.58	0.56	0.56	0.60	1.00	0.60	0.34	0.48	0.66	0.48			
Boron levels (kg/ha)													
0	28.45	26.34	32.06	29.61	39.36	31.59	21.61	27.13	36.76	39.56			
0.75	29.08	27.35	33.49	30.80	41.83	32.63	22.95	28.07	37.09	39.97			
1.50	29.86	28.15	34.73	32.63	43.01	33.39	23.47	28.38	38.14	40.02			
SEm +	0.21	0.20	0.20	0.21	0.36	0.22	0.12	0.17	0.24	0.17			
LSD (P=0.05)	0.58	0.56	0.56	0.60	1.00	0.60	0.34	0.48	0.66	0.48			
Absolute control	27.51	25.51	30.77	29.24	39.71	30.71	20.21	26.76	35.21	38.31			
Rest	29.13	27.28	32.42	31.01	41.40	32.53	22.67	27.86	37.33	39.85			
SEd +	0.52	0.35	0.49	0.53	0.88	0.53	0.30	0.42	0.42	0.20			
LSD (P=0.05)	1.05	0.70	0.98	1.07	1.77	1.07	0.60	0.84	0.84	0.40			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	B concentration (mg/kg DM)													
	2006													
	25 DAS			50 DAS			75 DAS			At harvest				
	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Root	Stem	Leaf	Seed
Nitrogen sources														
PU	32.36	28.73	33.59	33.92	44.21	41.34	24.97	28.26	36.31	40.72				
CAN	33.22	29.79	34.18	33.84	43.19	41.60	25.97	29.83	35.52	39.72				
SEM +	0.41	0.47	0.46	0.20	0.22	0.22	0.36	0.71	0.62	0.93				
LSD (P=0.05)	NS	NS	NS	NS	0.66	NS	NS	NS	NS	NS				NS
Sulphur levels (kg/ha)														
0	29.65	26.59	30.51	31.18	37.51	35.21	21.34	24.65	32.38	37.51				
25	32.78	28.58	33.62	33.91	43.79	41.69	24.51	29.82	35.65	40.66				
50	35.95	32.61	37.51	36.54	49.82	47.52	30.57	32.65	39.72	42.51				
SEM +	1.26	0.53	0.52	0.22	1.18	0.34	0.45	0.96	1.20	1.24				
LSD (P=0.05)	3.48	1.45	1.44	0.60	3.26	0.96	1.24	2.65	3.32	3.43				
Boron levels (kg/ha)														
0	29.31	22.72	25.91	27.44	34.46	34.80	21.12	23.31	30.67	37.54				
0.75	33.59	29.05	33.13	33.74	45.69	41.22	24.73	29.06	38.53	40.51				
1.50	35.66	36.02	42.60	40.48	50.96	48.40	30.57	34.76	38.53	42.61				
SEM +	1.26	0.53	0.52	0.22	1.18	0.34	0.45	0.96	1.20	1.24				
LSD (P=0.05)	3.48	1.45	1.44	0.60	3.26	0.96	1.24	2.65	3.32	3.43				
Absolute control	20.68	19.57	24.57	23.59	29.85	24.56	17.82	20.65	25.47	30.56				
Rest	32.79	29.26	33.88	33.88	43.70	41.47	25.47	29.04	35.91	40.22				
SED +	2.17	2.11	2.44	1.17	2.49	3.18	2.01	1.97	2.26	2.65				
LSD (P=0.05)	4.38	4.26	4.92	2.36	5.02	6.42	4.06	3.97	4.56	5.35				

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	B uptake (mg/plant)											
	2005											
	25 DAS			50 DAS			75 DAS			At harvest		
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Root	Leaf	Stem	Seed	Total	
Nitrogen sources												
PU	0.025	0.006	0.203	0.31	1.00	0.91	0.19	0.64	0.88	1.44	2.96	
CAN	0.025	0.007	0.201	0.32	1.09	0.90	0.19	0.74	0.88	1.46	3.08	
SEM ±	0.003	0.001	0.002	0.004	0.04	0.01	0.002	0.009	0.01	0.02	0.04	
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	0.25	NS	NS	NS	
Sulphur levels (kg/ha)												
0	0.024	0.004	0.187	0.23	1.00	0.80	0.17	0.61	0.80	1.40	2.80	
25	0.025	0.007	0.200	0.31	1.05	0.91	0.19	0.68	0.87	1.43	2.97	
50	0.026	0.008	0.219	0.40	1.07	1.01	0.21	0.79	0.97	1.54	3.29	
SEM ±	0.004	0.002	0.002	0.007	0.02	0.02	0.003	0.01	0.02	0.02	0.07	
LSD (P=0.05)	NS	NS	0.006	0.019	0.06	0.06	0.009	0.03	0.05	0.06	0.21	
Boron levels (kg/ha)												
0	0.023	0.005	0.189	0.28	0.89	0.83	0.18	0.65	0.77	1.29	2.71	
0.75	0.025	0.006	0.204	0.29	1.03	0.91	0.19	0.70	0.89	1.45	3.04	
1.5	0.027	0.008	0.214	0.37	1.20	0.98	0.20	0.73	0.97	1.62	3.32	
SEM ±	0.004	0.002	0.002	0.007	0.02	0.02	0.003	0.01	0.02	0.02	0.07	
LSD (P=0.05)	NS	NS	0.006	0.019	0.06	0.06	0.009	0.03	0.05	0.06	0.21	
Absolute control	0.014	0.002	0.164	0.17	0.67	0.64	0.14	0.40	0.60	0.94	1.94	
Rest	0.025	0.006	0.202	0.31	1.04	0.90	0.19	0.69	0.88	1.45	3.02	
SED ±	0.001	0.001	0.007	0.01	0.04	0.04	0.08	0.02	0.03	0.07	0.11	
LSD (P=0.05)	0.002	0.002	0.014	0.02	0.08	0.08	0.16	0.04	0.06	0.14	0.22	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	B uptake (mg/plant)													
	2006													
	25 DAS			50 DAS			75 DAS			At harvest				
	Leaf	Stem		Leaf	Stem		Leaf	Stem		Root	Leaf	Stem	Seed	Total
Nitrogen sources														
PU	0.036	0.008	0.26	0.54	1.24	1.44	0.33	0.87	1.32	1.39	1.32	1.39	3.58	
CAN	0.040	0.013	0.28	0.51	1.29	1.36	0.39	0.89	1.47	1.38	1.47	1.38	3.74	
SEM +	0.007	0.003	0.04	0.06	0.07	0.05	0.03	0.24	0.31	0.06	0.31	0.06	0.13	
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Sulphur levels (kg/ha)														
0	0.033	0.008	0.23	0.40	0.95	1.06	0.30	0.72	1.06	1.21	1.06	1.21	2.99	
25	0.037	0.012	0.27	0.51	1.28	1.39	0.32	0.87	1.43	1.39	1.43	1.39	3.69	
50	0.044	0.014	0.32	0.68	1.57	1.76	0.48	1.05	1.69	1.54	1.69	1.54	4.28	
SEM +	0.001	0.001	0.003	0.06	0.20	0.13	0.04	0.09	0.17	0.08	0.17	0.08	0.10	
LSD (P=0.05)	0.003	0.003	0.009	0.18	0.59	0.40	0.12	0.27	0.49	0.23	0.49	0.23	0.29	
Boron levels (kg/ha)														
0	0.027	0.008	0.20	0.33	0.97	1.01	0.26	0.69	1.02	1.24	1.02	1.24	2.95	
0.75	0.038	0.010	0.27	0.49	1.21	1.42	0.33	0.92	1.39	1.40	1.39	1.40	3.71	
1.5	0.049	0.015	0.35	0.76	1.65	1.79	0.48	1.03	1.76	1.52	1.76	1.52	4.31	
SEM +	0.001	0.001	0.003	0.06	0.20	0.13	0.04	0.09	0.17	0.08	0.17	0.08	0.10	
LSD (P=0.05)	0.003	0.003	0.009	0.18	0.59	0.40	0.12	0.27	0.49	0.23	0.49	0.23	0.29	
Absolute control	0.014	0.005	0.17	0.31	0.64	0.83	0.21	0.43	0.87	0.89	0.87	0.89	2.19	
Rest	0.038	0.011	0.27	0.53	1.26	1.40	0.36	0.88	1.39	1.38	1.39	1.38	3.65	
SED ±	0.002	0.003	0.07	0.11	0.01	0.04	0.07	0.10	0.09	0.11	0.09	0.11	0.13	
LSD (P=0.05)	0.004	0.006	0.14	0.22	0.02	0.08	0.14	0.20	0.18	0.22	0.18	0.22	0.26	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

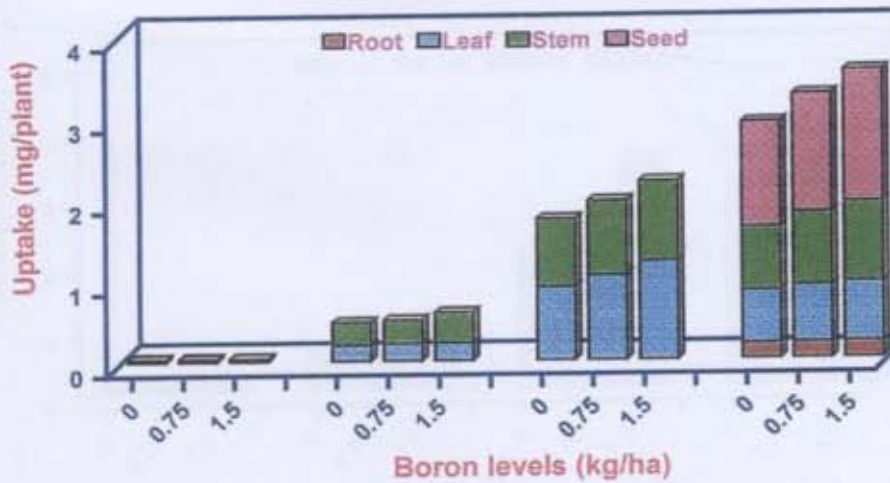
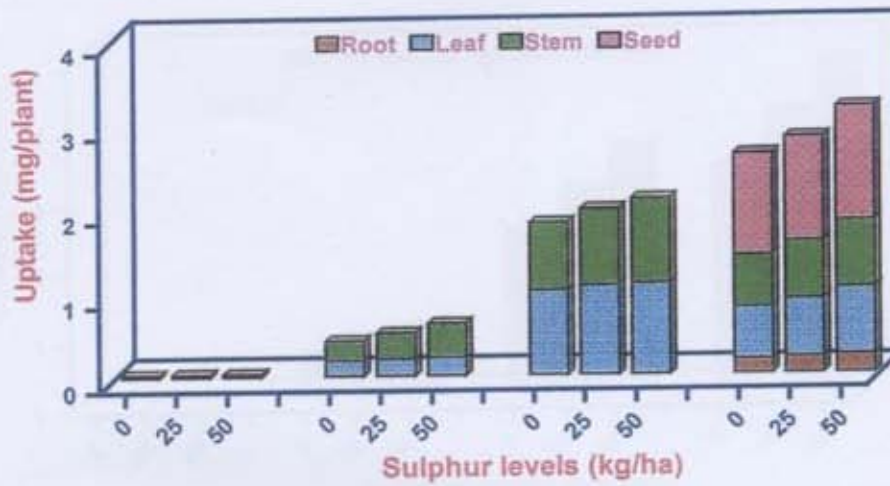
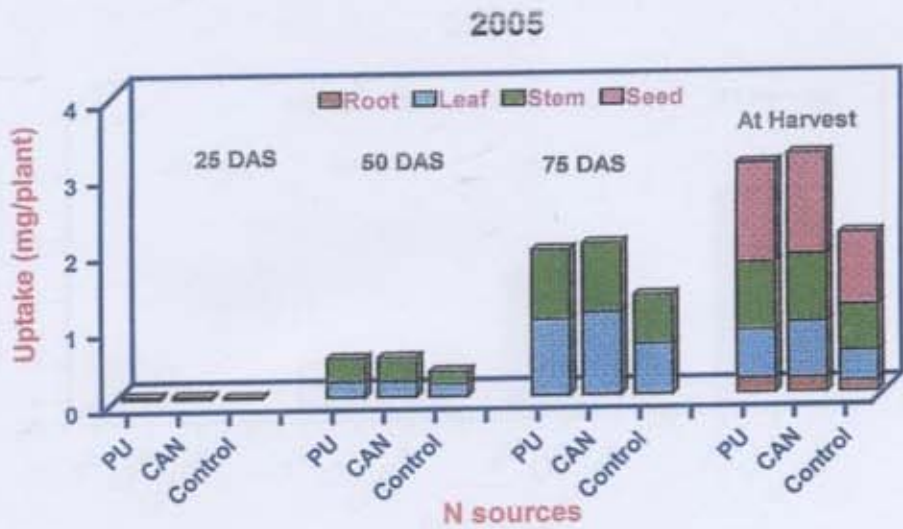


Fig. 17. Boron uptake per plant by sunflower as influenced by nitrogen sources, sulphur and boron levels (2005)

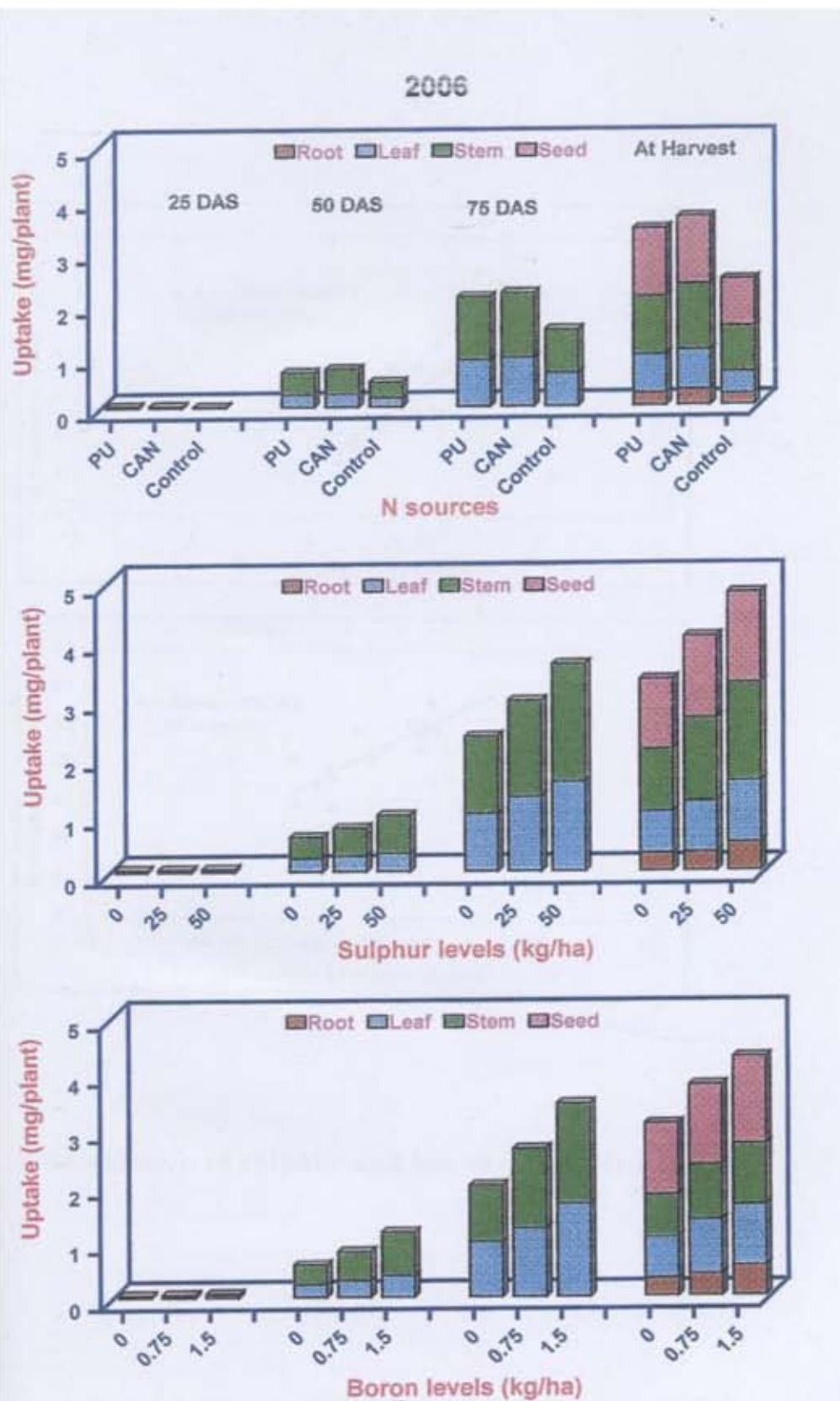


Fig. 18. Boron uptake per plant by sunflower as influenced by nitrogen sources, sulphur and boron levels (2006)

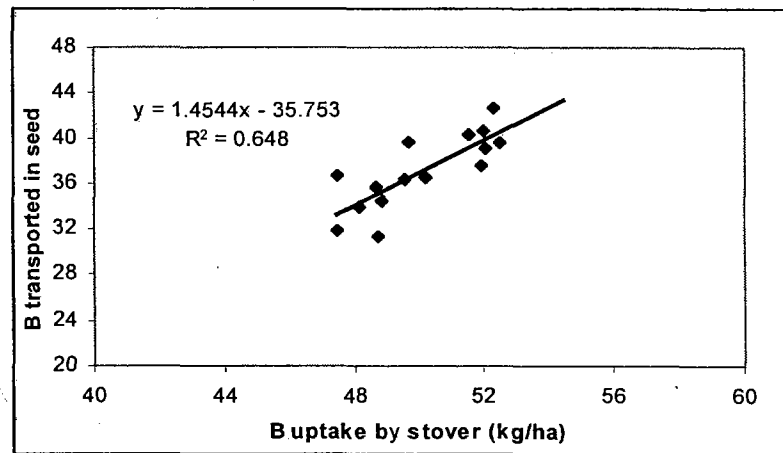
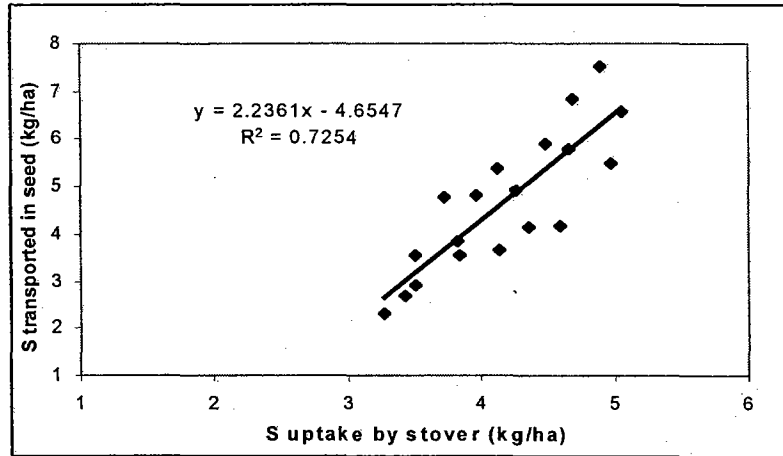


Fig 19. Accumulation of sulphur and boron in seed from stover



Comparison between absolute control and boron application on sunflower



**Comparison between control and best treatment
(N₈₀S₅₀B_{1.5})**

sharply. B uptake in leaves is higher than stem only at 25 DAS and after that stem recorded the higher uptake till harvest stage. At 50 and 75 DAS, S and B application improved the statistics with regard to B uptake with the first dose found to be more pronounced. At harvest stage, during both the years, B uptake was higher with seeds. The effect of S application on B uptake by seed was significant but not as influential as that of B. B application had a sharp influence on B uptake by the seed. The response was positive with application @ 1.5 kg B/ha as well. Without any surprise, all the treatments were significantly superior than absolute control where no fertilization was done.

B uptake in seed can be related to B uptake by stover as:

$$Y = 1.4544 (x) - 35.75$$

$$R^2 = 0.68$$

Where, Y = B uptake by seeds (kg/ha)

x = B uptake by stover (kg/ha)

4.1.5.11 Total nutrient uptake by sunflower

The uptake of different nutrients by sunflower is calculated separately in seed and stover which is presented in Table 40, 41 and Fig. 20.

4.1.5.11.1 N uptake

N uptake was more in seed than stover during both the years of the study. The N uptake in seed and total N uptake was significantly influenced by different sources of N during 2005 and 2006. But N uptake by stover was not significantly different through any of the N source during both 2005 and 2006. S application enhanced the N uptake during both the years, but more increase was recorded in N uptake by the seed. In seed, N uptake was more quick with S application @ 25 kg/ha, although it increased up to 50 kg S/ha but the response was slow. Here the N uptake enhancement through different S levels was in a steady increasing trend during both the years. B also increased N uptake both in seed and stover but the increase was less than that of S. B application @ 0.75 kg/ha gave more quick N uptake than 1.5 kg B/ha, while all the treatments were significantly superior than absolute control which experienced the lowest N uptake in seed, stover as well as total uptake.

Treatments	2005														
	N (kg/ha)			P (kg/ha)			K (kg/ha)			S (kg/ha)			B (g/ha)		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
Nitrogen sources															
PU	61.29	18.02	77.32	16.07	5.49	21.56	41.28	53.10	94.38	4.58	3.94	8.52	76.57	67.29	142.36
CAN	63.87	18.98	85.84	16.74	5.93	22.67	43.65	56.36	100.01	4.91	4.32	9.23	75.91	70.19	147.60
SEM ±	0.64	0.32	0.23	0.59	0.61	3.08	2.11	4.46	5.52	0.11	0.12	0.17	0.81	0.63	1.27
LSD (P=0.05)	1.77	NS	0.63	NS	NS	NS	NS	NS	NS	0.32	0.33	0.47	NS	1.74	3.51
Sulphur levels (kg/ha)															
0	57.56	17.63	75.18	14.89	4.78	19.64	38.20	52.60	90.80	3.76	3.58	7.34	70.07	67.23	137.30
25	63.95	18.49	82.43	16.87	5.70	22.58	43.56	55.00	98.56	4.89	3.84	8.74	78.36	68.31	146.67
50	66.23	19.40	85.62	17.46	6.65	24.12	45.63	56.59	102.22	5.59	4.98	10.57	80.30	70.69	150.99
SEM ±	1.92	0.41	1.25	0.23	1.14	3.41	1.93	1.28	1.25	0.15	0.14	0.44	2.15	0.17	0.78
LSD (P=0.05)	5.32	1.16	3.47	0.66	NS	NS	5.35	3.35	3.47	0.45	0.40	1.23	5.96	0.48	2.28
Boron levels (kg/ha)															
0	58.59	16.90	75.49	14.96	4.69	19.31	38.15	50.40	88.55	3.46	3.67	7.11	72.21	64.40	136.61
0.75	62.18	18.92	81.10	16.35	5.88	21.90	42.78	55.62	98.40	4.75	4.14	8.88	76.00	69.49	145.49
1.50	66.99	19.70	86.69	17.90	6.58	22.14	46.48	58.17	104.64	6.03	4.60	10.62	80.51	72.34	152.85
SEM ±	1.92	0.41	1.25	0.23	1.14	3.41	1.93	1.28	1.25	0.15	0.14	0.44	2.15	0.17	0.78
LSD (P=0.05)	5.32	1.16	3.47	0.66	NS	NS	5.35	3.35	3.47	0.45	0.40	1.23	5.96	0.48	2.28
Absolute control	33.14	15.85	48.97	8.19	2.72	10.93	20.97	43.92	64.89	1.77	2.67	4.46	42.97	58.93	101.97
Rest	62.58	18.50	81.09	16.40	5.71	22.12	42.46	54.73	97.19	4.74	4.13	8.87	76.24	68.74	144.98
SEM ±	4.06	0.97	4.86	1.17	1.23	1.06	4.94	1.06	1.93	0.80	0.25	1.28	3.01	1.17	2.44
LSD (P=0.05)	8.20	1.95	9.29	2.36	2.70	2.14	9.97	2.14	3.89	1.60	0.50	2.58	6.02	2.36	4.92

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Treatments	2006														
	N (kg/ha)			P (kg/ha)			K (kg/ha)			S (kg/ha)			B (g/ha)		
	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total	Seed	Stover	Total
Nitrogen sources															
PU	57.77	23.41	81.37	15.15	4.90	20.04	38.33	52.20	90.53	4.85	3.90	8.75	74.80	64.49	139.30
CAN	64.54	27.05	91.42	16.31	5.64	21.96	42.02	58.74	100.76	5.29	4.71	10.01	76.26	70.81	147.08
SEm +	0.29	2.43	2.17	1.32	0.47	2.83	2.06	2.11	3.16	0.32	0.93	0.61	1.41	3.62	2.41
LSD (P=0.05)	1.44	NS	6.01	NS	NS	NS	NS	5.84	NS	NS	NS	NS	NS	NS	6.67
Sulphur levels (kg/ha)															
0	53.94	21.52	75.41	13.93	4.29	18.24	34.05	49.16	83.21	4.15	3.46	7.62	64.90	54.83	119.76
25	61.76	25.32	87.06	15.98	5.29	21.26	40.56	54.55	95.11	5.10	3.75	8.84	76.86	68.50	145.38
50	67.78	28.86	96.64	17.28	6.23	23.50	45.90	62.71	108.61	5.98	5.70	11.67	84.83	79.62	164.48
SEm +	0.85	2.30	3.99	1.99	1.69	2.81	4.77	6.13	5.24	0.12	0.07	0.70	1.62	3.99	4.10
LSD (P=0.05)	2.51	6.38	11.09	NS	NS	NS	NS	NS	14.51	0.35	0.21	2.00	4.51	11.06	11.36
Boron levels (kg/ha)															
0	52.10	22.42	74.50	13.84	4.05	17.89	31.91	47.67	79.58	3.88	3.28	7.16	64.76	52.17	116.94
0.75	62.54	25.23	87.77	15.74	5.46	21.20	41.38	56.74	98.12	5.02	4.41	9.43	76.54	71.05	147.58
1.5	68.86	28.06	96.90	17.63	6.30	23.93	47.22	62.02	109.24	6.32	5.22	11.55	85.30	79.73	165.04
SEm +	0.85	2.30	3.99	1.99	1.69	2.81	4.77	6.13	5.24	0.12	0.07	0.70	1.62	3.99	4.10
LSD (P=0.05)	2.51	NS	11.09	NS	NS	NS	NS	NS	14.51	0.35	0.21	2.00	4.51	11.06	11.36
Absolute control	31.34	16.96	48.31	8.23	2.63	10.86	16.37	39.78	56.15	1.97	3.21	5.18	37.57	43.81	77.38
Rest	61.16	25.23	86.39	15.73	5.27	21.00	40.17	55.47	95.64	5.07	4.30	9.38	75.53	67.65	143.19
SEd +	2.13	2.82	4.79	2.23	1.88	3.77	5.77	6.33	4.10	0.71	1.02	0.89	2.61	4.13	11.31
LSD (P=0.05)	5.98	7.91	13.28	4.50	3.79	7.61	11.65	12.78	8.28	1.43	2.06	1.79	5.27	8.34	22.84

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

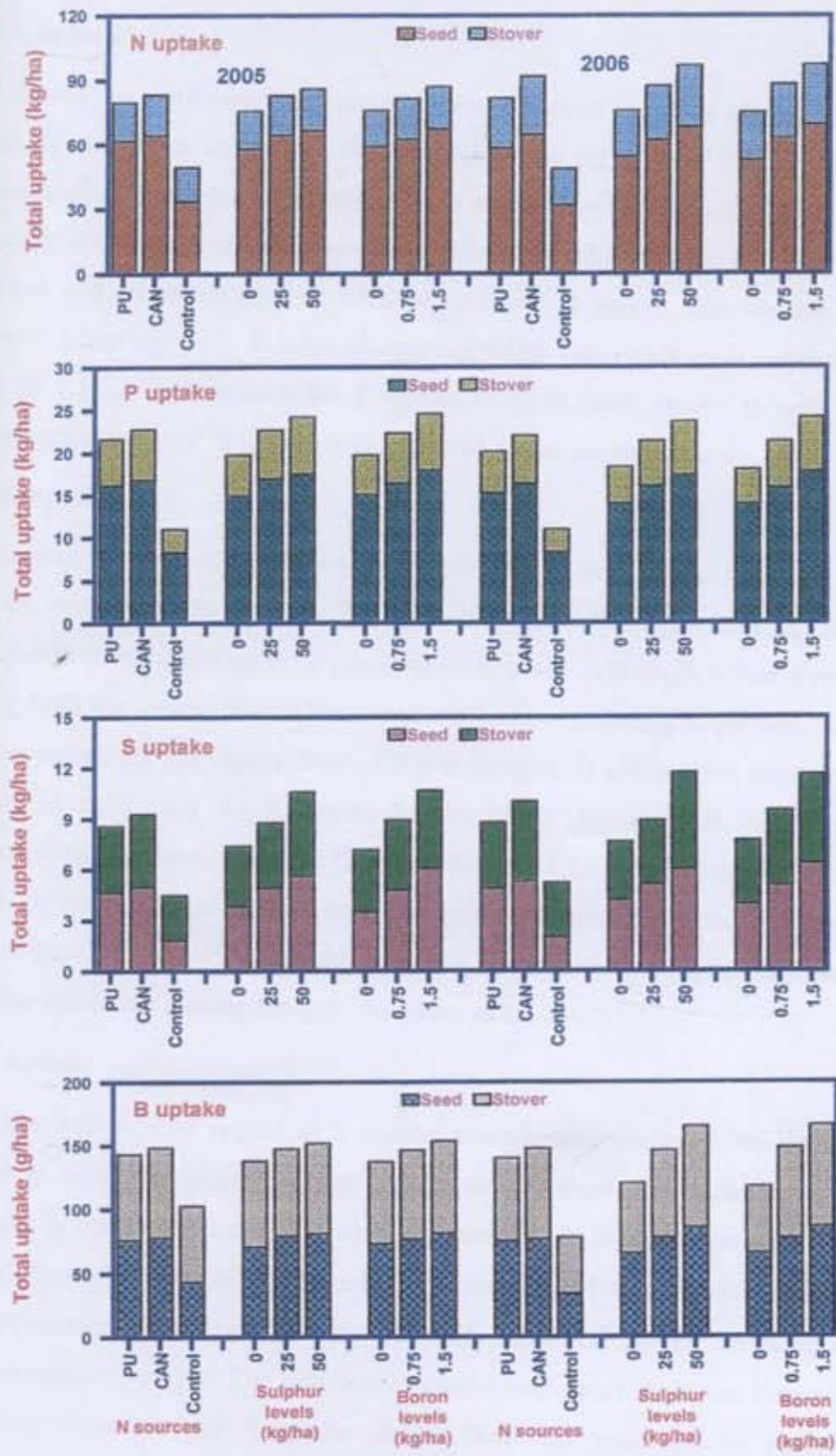


Fig. 20. Total nutrient uptake by sunflower as influenced by nitrogen sources, sulphur and boron levels

4.1.5.11.2 P uptake

P uptake by sunflower crop revealed that the seed removes almost 3 times P than stover. During both the years, the P uptake was influenced by application of various treatments. N sources were not able to cause any significant difference in P uptake by crop during any of the season. S application enhanced the P uptake around 14.7% in seed and an increase up to 40% was noticed in stover. The similar level of increment was observed with B also. Crop responded very well to B application. B application @ 1.5 kg/ha enhanced the P uptake by both seed, stover as well as total uptake. The similar trend of N uptake was followed in the second year also.

4.1.5.11.3 K uptake

K uptake by sunflower followed a reverse pattern than N and P. The K uptake was higher by stover than by seed. In 2005 and 2006, both the N sources i.e. urea and CAN were found to be statistically at par with each other. Although S had a profound effect during both the years, more clear response was seen during application of S @ 25 kg/ha. The increment for higher dose of S was meagre. B application also proved to be significant in enhancing the K uptake by the crop. The per cent increment was higher in seed than in stover. The total K uptake followed the same pattern of K uptake of seed and stover individually and was higher with increasing doses of S and B. Following the previous pattern, K uptake in all the treatments was higher than absolute control and the trend was similar for both the years of the study.

4.1.5.11.4 S uptake

All the values with regard to S uptake were higher during 2006 than 2005. The S uptake in seed was slightly higher than by stover during both the years of the study. S uptake in seed, stover and total uptake remained statistically non-significant in 2006 due to different sources of N, where both urea and CAN were significantly equal. Due to S application the S uptake ratio between seed and stover declined at the respective increase in S levels. The increase in uptake was more in stover than seed. B application also enhanced the S uptake during both the years of the study. The difference due to B application was more prominent at application of 0.75 kg/ha than the higher dose of 1.5 kg B/ha. Here also higher B dose gave more chance to stover for

higher S uptake but of course, all treatments were superior than absolute control during both the years of the field trial.

4.1.5.11.5 B uptake

B uptake in seed, stover and total uptake followed the similar pattern like the other nutrients. The B uptake was higher in seed than in stover during both the years of study. Control here also, was not able to compete with other treatments. N sources either urea or CAN was able to make a difference in B uptake by stover in 2005 but not in 2006. S application, improved B uptake at both doses during both the years of the study, however, increase was more at application of 25 kg S/ha. Without any surprise B application increased the B uptake at both the levels. Above all, both B doses had a similar result in B uptake and the response was linear. Important thing to be noticed here is that the ratio of B uptake between seed and stover remained almost similar for both the doses of B. The results were confirmed due to similar pattern followed by the crop during both the years of field trial.

4.1.5.12 Nutrient use-efficiency

It is calculated as increase in seed yield per unit increase in input uptake (per kg N, S, B uptake) which is presented in Fig. 21.

Nutrient use-efficiencies of various nutrients like N, P, K, S and B were quantified as following equations.

A. Seed yield and N uptake

The relationship was positive and can be written as:

$$Y = 16.922 (x) + 380.23$$

$$R^2 = 0.89$$

Where, Y = Seed yield (kg/ha)

x = Total N uptake (kg/ha)

The efficiency of conversion is 16.922%.

B. Seed yield and P uptake

The seed yield also increased with increasing P uptake by the crop as:

$$Y = 48.402 x + 829.24$$

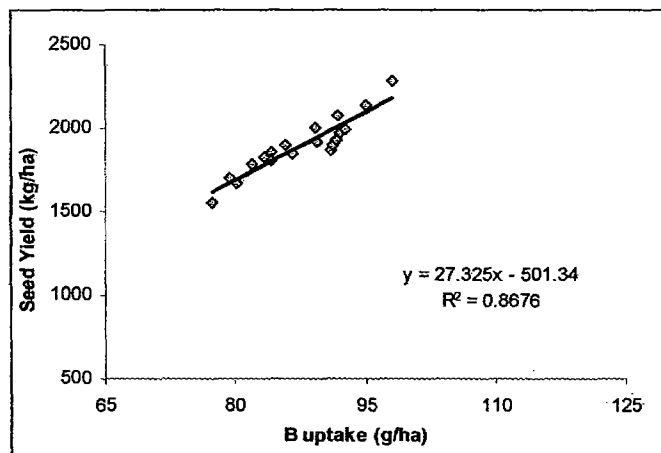
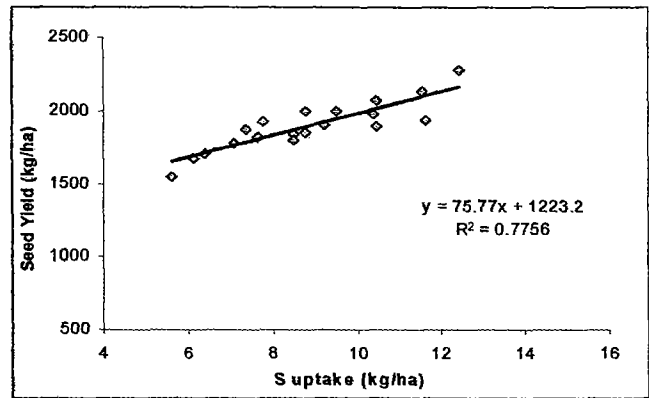
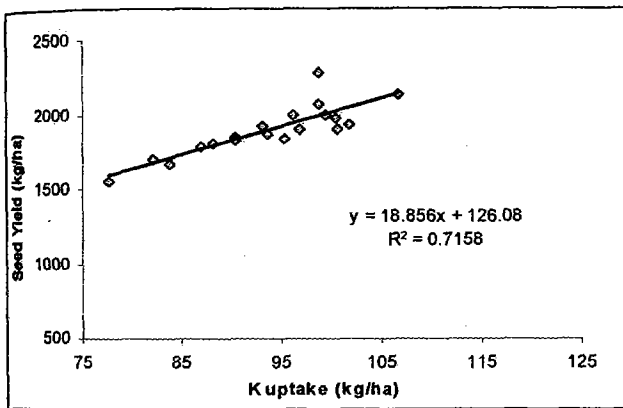
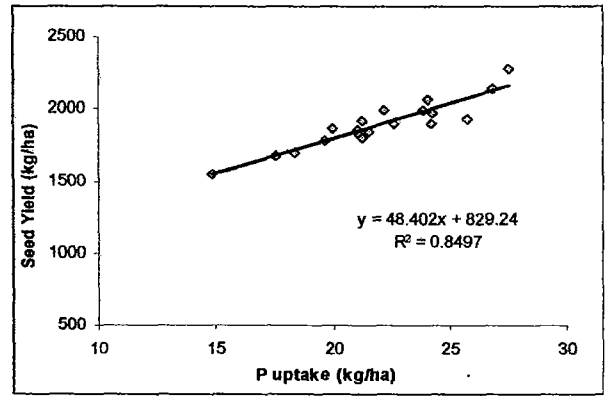
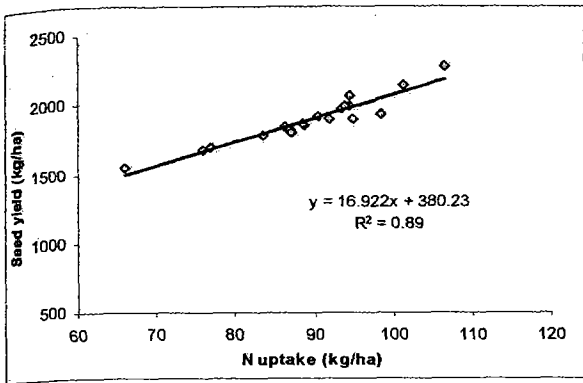


Fig.21. Nutrient use efficiencies of different nutrients

$$R^2 = 0.84$$

Where, Y = Seed yield (kg/ha)

x = Total P uptake (kg/ha)

The efficiency of conversion falls around 48.40%.

C. Seed yield and K uptake

The seed yield was enhanced with increasing K uptake but the efficiency of conversion to final produce was 18.85% only.

$$Y = 18.856 (x) + 126.08$$

$$R^2 = 0.71$$

Where, Y = Seed yield (kg/ha)

x = Total K uptake (kg/ha)

D. Seed yield and S uptake

Seed yield was positively correlated with S uptake as:

$$Y = 75.77 (x) + 1223.2$$

$$R^2 = 0.77$$

Where, Y = Seed yield (kg/ha)

x = Total S uptake (kg/ha)

The efficiency of conversion was 75.77%

E. Seed yield and B uptake

The positive relationship between seed yield and B uptake can be quantified as:

$$Y = 27.325 (x) - 501.34$$

$$R^2 = 0.86$$

Where, Y = Seed yield (kg/ha)

x = Total B uptake (g/ha)

4.1.6 Available nutrient status of soil after harvest of sunflower

Data pertaining to the residual nutrient status of soil after the harvest of each year crop of sunflower is given in Table 42 and 43. Available status of five elements i.e., N, P, K, S and B were estimated at 3 depths of soil i.e. 0-20 cm, 20-40 cm and 40-60 cm during 2005 and 2006.

4.1.6.1 Available N

The available N status after the harvest of sunflower was analyzed. In 2005, the N application through urea and CAN was not able to make any significant difference in the residual available N. The amount of available N decreased as the soil depth increased during both the years. S application was also efficient in making a significant difference to enhance the available N status of soil. During both the years more difference was caused at 0-20 cm depth as the depth increased the effect was diluted and not much difference was observed at 40-60 cm soil depth. Similarly B application also enhanced the amount of residual N. The increase was more prominent at 0-20 cm depth and application of boron @ 1.5 kg/ha could enhance even up to 6-7 kg available N/ha for 20-40 cm depth, the change was moderate about 4-5 kg available N/ha in the middle layer, which remained only 3-4 kg available N/ha at 40-60 cm depth during both the years. For control plots, all the layers experienced a lower amount of available N in kg/ha in 2006 which was increased significantly up to a reasonable level due to application of N, S or B when both years trials were studied.

4.1.6.2 Available P

Average data on available P showed that the amount of available P increased with increase in depth during both the years. None of the N sources was able to cause an effect which could be significantly different than each other. Both urea and CAN remained statistically at par with each other. Although application of different levels of S could bring a reasonable change but it was in negative side. Application of S at higher dose reduced the available P kg/ha in 0-20, 20-40 and 40-60 cm depth of soil as well. Here also the reduction in available P kg/ha was not significant at 20-40 and 40-60 cm soil depth. The change was noticed in the upper layer only. During both the years of experimentation, B also followed the same trend. It was also able to make a significant difference only in the upper layer and not in the deeper layers. The effect

2005

Treatments	Available N (kg/ha)			Available P (kg/ha)			Available K (kg/ha)			Available S (kg/ha)			Available B (mg/kg)		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Nitrogen sources															
PU	158.18	147.00	142.16	13.34	14.44	16.15	237.56	244.49	244.49	37.13	38.05	41.96	1.41	2.34	2.87
CAN	159.56	145.45	144.92	12.68	13.95	16.15	238.94	245.77	245.77	37.82	38.25	42.90	1.40	2.33	2.99
SEM ±	1.81	1.05	1.01	0.37	0.40	0.44	0.40	3.22	3.27	0.30	0.31	0.37	0.01	0.02	0.03
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.09
Sulphur levels (kg/ha)															
0	154.45	143.45	141.13	13.86	14.31	16.37	239.05	245.01	250.33	35.53	36.40	40.41	1.26	2.29	2.89
25	159.65	145.53	142.88	12.70	14.18	16.06	238.43	245.11	249.19	37.40	38.23	42.10	1.48	2.29	2.93
50	162.51	149.71	146.61	12.47	14.10	16.01	237.26	245.27	248.99	39.53	39.86	44.78	1.55	2.40	2.99
SEM ±	2.22	1.11	1.07	0.45	0.49	0.64	4.22	3.94	4.01	0.36	0.38	0.45	0.02	0.03	0.04
LSD (P=0.05)	6.06	3.07	2.88	1.27	NS	NS	NS	NS	NS	1.02	1.06	1.26	0.06	0.09	0.12
Boron levels (kg/ha)															
0	155.93	143.35	142.94	14.24	14.52	16.05	240.05	246.76	250.53	36.65	35.01	40.31	1.17	1.96	2.74
0.75	158.86	148.24	142.89	13.12	14.10	16.02	238.08	245.17	249.33	37.42	37.13	42.25	1.38	2.33	2.99
1.50	161.86	147.10	144.80	11.68	13.96	16.37	236.63	243.45	248.63	38.38	39.36	44.73	1.75	2.69	3.07
SEM ±	2.22	1.11	1.07	0.45	0.49	0.64	4.22	3.94	4.01	0.36	0.38	0.45	0.02	0.03	0.04
LSD (P=0.05)	6.06	3.07	2.88	1.27	NS	NS	NS	NS	NS	1.02	1.06	1.26	0.06	0.09	0.12
Absolute control	142.60	130.24	125.41	14.27	13.21	10.32	242.50	247.81	250.92	31.40	32.60	37.50	1.20	2.09	2.99
Rest	158.87	146.23	143.54	13.01	14.19	16.15	238.25	245.13	249.5	38.16	37.16	42.43	1.43	2.33	2.93
SED ±	4.81	5.26	4.83	1.33	0.85	1.85	10.34	9.66	5.67	0.86	0.94	1.11	0.08	0.08	0.10
LSD (P=0.05)	9.71	10.62	9.75	2.62	1.71	3.73	NS	NS	NS	1.73	1.89	2.24	0.16	0.16	0.20

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

0-20 cm 20-40 cm 40-60 cm

N (kg/ha)	166.21	152.21	145.76
P (kg/ha)	16.42	15.41	16.51
K (kg/ha)	251.36	257.51	260.28
S (kg/ha)	24.51	26.79	28.27
B (mg/kg)	0.98	1.11	1.29

Treatments	2006															
	Available N (kg/ha)			Available P (kg/ha)			Available K (kg/ha)			Available S (kg/ha)			Available B (mg/kg)			
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60	
Nitrogen sources																
PU	179.08	174.68	165.17	11.84	9.92	9.38	224.35	230.23	228.26	38.61	38.86	40.89	1.34	2.20	2.72	
CAN	182.54	176.30	172.27	12.03	10.03	9.49	223.69	229.45	226.98	38.26	39.39	42.44	1.44	2.10	2.79	
SEM ±	1.01	0.37	1.21	0.22	0.45	0.38	1.52	0.49	0.36	0.68	0.27	0.42	0.04	0.04	0.04	
LSD (P=0.05)	3.02	1.01	3.35	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Sulphur levels (kg/ha)																
0	178.08	174.51	164.73	12.24	10.17	9.91	229.29	234.91	232.61	34.21	33.84	36.04	1.37	2.04	2.65	
25	182.05	175.62	169.82	12.09	9.97	9.37	222.30	230.27	227.59	38.20	38.94	41.28	1.39	2.13	2.74	
50	183.63	176.32	171.63	11.48	9.77	9.03	220.51	224.36	222.68	42.78	44.60	47.08	1.42	2.28	2.89	
SEM ±	1.17	0.45	1.32	0.45	0.53	0.47	5.01	4.11	3.39	1.33	1.45	2.15	0.05	0.06	0.05	
LSD (P=0.05)	3.22	1.27	3.66	NS	NS	NS	NS	NS	NS	3.68	4.01	5.95	NS	0.18	0.15	
Boron levels (kg/ha)																
0	179.52	174.45	163.93	12.31	10.11	9.68	228.61	234.40	231.55	36.82	37.82	40.02	1.30	2.04	2.53	
0.75	181.63	176.23	168.70	11.97	9.91	9.48	222.56	230.44	227.81	38.51	39.45	41.56	1.38	2.17	2.80	
1.50	182.11	175.76	173.53	11.51	9.63	9.14	220.91	224.68	223.52	39.96	40.11	42.79	1.49	2.29	2.93	
SEM ±	1.17	0.45	1.32	0.45	0.53	0.47	5.01	4.11	3.39	1.33	1.45	2.15	0.05	0.06	0.05	
LSD (P=0.05)	3.22	1.27	3.66	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.15	0.18	0.15	
Absolute control	160.54	154.28	140.62	11.26	9.28	9.13	222.59	220.65	223.92	35.92	36.82	33.52	1.12	1.98	2.47	
Rest	181.08	175.48	168.72	11.93	9.97	9.43	224.02	229.84	227.62	38.43	39.12	41.45	1.39	2.15	2.75	
SED ±	3.75	2.29	4.80	0.45	0.61	0.54	6.11	5.16	3.28	1.37	0.86	3.11	0.06	0.08	0.07	
LSD (P=0.05)	7.57	4.62	9.69	NS	NS	NS	NS	NS	NS	2.76	1.73	6.28	0.12	0.16	0.14	

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Initial nutrient status

	0-20 cm	20-40 cm	40-60 cm
N (kg/ha)	188.27	180.57	171.52
P (kg/ha)	15.13	13.27	10.81
K (kg/ha)	245.19	265.83	285.53
S (kg/ha)	22.52	24.71	26.52
B (mg/kg)	0.96	1.02	1.18

was diluted but significant enough than absolute control during both the years of the field trials.

4.1.6.3 Available K

The status of available K in soil followed the same trend like that of P. It was found the highest in the upper layer of 0-20 cm and declined thereafter, with increase in soil depth. The decline was sharper during 2005 than 2006. In 2005, all the treatments were at par with control. No significant difference could be seen on application of any fertilizer treatment regarding N, S or B. In 2006, the difference was seen because of N, S and B when compared with absolute control only. Otherwise the different treatments of N sources, levels of S and B were at par with each other although a slight decrease was noticed numerically with increasing doses but statistically non-significant.

4.1.6.4 Available S

Since S was applied during the field trial, the average data revealed that the amount of available S increased with increase in depth from 0-20 to 40-60 cm. N application through urea or CAN could not bring any significant change during any of the years of the study, although the amount of available S was higher during the first year. Application of S brought significant change in level of available S at all the depths of soil. The pace of increment remained almost same for both the years. During 2005, about 10-12 kg available S/ha was enhanced in 0-20 cm soil depth while it was about 12-14 kg available S/ha for the second year. More change was noticed in the upper layer only and the effect of S application diluted with increasing depth of soil, although remained significant due to application of fertilizer treatments than absolute control. B was also able to enhance the level of available S/ha. A change of about 2-3 kg S/ha and 4-5 kg S/ha was noticed due to B application in 2005 and 2006, respectively which was quite higher than that in control.

4.1.6.5 Available B

The status of available B in soil was estimated and analyzed for 3 depths of soil. A careful observation of the data revealed that the status of available B increased with increase in depth of soil from 0-20 cm to 40-60 cm soil depth. Here also, following the similar trend, N sources could not make any significant difference

whether urea or CAN was applied during both the years of the study. Application of S had a positive effect on available B enhancement in soil.

B was an important change causing element during both the years. In 2005, a change of 0.58 mg/kg was noticed in 0-20 cm depth of soil and surprisingly the change was more pronounced for the deeper layer. At 40-60 cm, a 0.33 mg/kg increment was noticed. Following the same trend in 2006, the available B status enhanced from 0.19 mg/kg in upper layer to about 0.4 mg/kg for the deeper soil layer. All the fertilizer treatments were superior than absolute control during both the crop seasons.

4.1.7 Monetary returns from sunflower

Monetary returns in terms of net returns and B: C ratio is presented in Table 44 and 45. The results showed superiority of all the treatments over control except with CAN and S @ 50 kg/ha. All the economic parameters were higher during the first year. N sources were able to make a significant difference. In both the years urea proved to be a significantly superior source and reflected a higher benefit: cost ratio (B:C ratio) about 2.30 in 2005 and 2.14 in 2006. Gross returns were almost similar but net returns were higher with urea than CAN in both the years of the study.

S application was beneficial in terms of net returns and B:C ratio, but the beneficial effect was seen only up to 25 kg S/ha. At the higher dose, the returns declined even the B:C ratio became narrower than control. With B, net returns were higher even up to 5,000 Rs/ha. The lower dose i.e. 0.75 kg/ha proved better to give the higher returns, highest being at 1.5 kg B/ha. The next best treatment in respect of net returns and B:C ratio was S application @ 50 kg/ha during both the years. The economic optimum dose for S was 38.15 and 72.87, respectively for 2005 and 2006.

Table 45. Effect of N sources, S and B levels on economic analysis of S application in sunflower

Economic parameters	2005	2006
Economic optimum dose (kg)	38.1	72.9
Maximum yield dose (kg)	46.5	93.7
Response to economic optimum dose	209.3	334.1
Response (kg/kg S)	5.5	4.6

cost ratio of sunflower crop

Treatments	2005				2006			
	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
Nitrogen sources								
PU	10933.7	36188.9	25255.15	2.30	11044.83	34808.97	23790.0	2.14
CAN	13329.8	37106.9	23776.15	1.78	13337.06	35886.27	22592.1	1.68
SEm +	131.37	299.94	256.84	0.01	142.69	373.88	243.73	0.02
LSD (P=0.05)	364.16	831.41	711.99	0.05	397.53	1036.36	675.59	0.06
Sulphur levels (kg/ha)								
0	11913.2	34364.7	22481.5	1.92	11898.1	32953.28	21606.4	1.78
25	12218.2	35958.2	23678.5	1.95	12203.1	35015.27	22571.4	1.88
50	12264.0	39610.8	27386.7	2.26	12471.5	38074.40	25395.5	2.07
SEm +	168.90	367.35	314.59	0.02	174.76	457.71	298.51	0.02
LSD (P=0.05)	446.01	1018.26	872.88	0.06	484.43	1269.27	827.43	0.07
Boron levels (kg/ha)								
0	11523.2	31380.9	22896.8	2.00	11508.1	30002.84	21486.8	1.86
0.75	12218.2	38859.0	24648.8	2.03	12283.1	37906.12	23782.9	1.93
1.5	12654.0	39704.7	26849.2	2.10	12861.38	38133.90	24305.7	1.96
SEm +	168.90	367.35	314.59	0.02	174.76	457.71	298.51	0.02
LSD (P=0.05)	446.01	1018.26	872.88	0.06	484.43	1269.27	827.43	0.07
Absolute control	8971.55	22118.44	13146.89	1.46	8956.50	21898.85	16942.3	1.89
Rest	12131.8	36647.94	24798.2	2.04	12217.52	35347.62	23191.1	1.91
SEd +	322.55	924.49	791.78	0.05	437.82	793.13	638.30	0.04
LSD (P=0.05)	651.55	1867.46	1599.39	0.10	886.41	1602.12	1289.36	0.08

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Profit (Rs)	2,185.1	3,165.0
Returns (Rs/Re)	2.3	1.7

Response equation for S:

$$2005: Y=1787.60+9.3x-0.1x^2$$

$$2006: Y=1730.40+7.5x-0.04x^2$$

Where, Y= yield (kg/ha) and x= S application (kg/ha)

4.1.8 Production functions for sunflower

It represents the input-output matrix which was developed to quantify the role of different nutrients in growth, yield and quality of sunflower crop. The relationships obtained as follows:

A. $LAI_{max} = 4.016 + 0.0139 S \text{ applied} + 0.3262 B \text{ applied}$

B. $\text{Total dry matter(g)} = 7264.63 + 29.146 S \text{ applied} + 824.604 B \text{ applied}$

C. $\text{Seed yield (kg/ha)} = 1685.84 + 4.1728 S \text{ applied} + 53.649 B \text{ applied}$

D. $\text{Oil yield (kg/ha)} = 650.55 + 3.8880 S \text{ applied} + 126.66 B \text{ applied}$

E. $\text{Protein yield (kg/ha)} = 308.71 + 1.8164 S \text{ applied} + 57.3079 B \text{ applied}$

Here the doses of S and B applied were in (kg/ha)

All these production functions can be fitted to an existing nutrient model to develop a dynamic sub-routine for sunflower for the validation of existing model. The part of the model related to nutrient application and nutrient uptake with soil status can be worked out with the above-mentioned production functions.

4.2 Mungbean

Effect of fertilization and nutrient management in sunflower was studied and its residual effect on succeeding mungbean crop in sunflower-mungbean cropping system was seen during 2005 and 2006.

4.2.1 Growth parameters and yield attributes

Various growth parameters and yield attributes of mungbean are presented in Table 46 and 47.

Table 46. Residual effect of nitrogen sources, sulphur and boron levels on yield attributes, yields and harvest index of succeeding mungbean in sunflower-mungbean cropping system (2005)

Treatments	2005						
	Plant height (cm)	Number of branches/plant	Number of pods/plant	Number of grains/pod	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
Nitrogen sources							
PU	40.3	26.0	24.5	8.2	883.3	4117.6	17.6
CAN	46.0	29.7	26.0	8.4	897.4	4211.9	17.5
SEM +	0.65	0.35	0.34	0.11	12.01	21.00	0.32
LSD (P=0.05)	1.81	0.97	0.94	NS	NS	58.17	NS
Sulphur levels (kg/ha)							
0	38.1	25.5	20.6	8.0	824.9	4015.4	17.0
25	42.3	27.8	26.2	8.3	861.1	4131.5	17.2
50	49.1	30.3	28.8	8.5	985.2	4347.5	18.4
SEM +	0.80	0.43	0.44	0.14	14.04	21.03	0.39
LSD (P=0.05)	2.22	1.19	1.22	0.39	38.89	58.25	1.08
Boron levels (kg/ha)							
0	41.2	24.0	23.0	7.9	850.3	3987.3	17.5
0.75	43.1	27.8	25.4	8.3	887.5	4174.5	17.5
1.50	45.1	31.6	27.4	8.7	933.5	4332.6	17.7
SEM +	0.80	0.43	0.44	0.14	14.04	21.03	0.39
LSD (P=0.05)	2.22	1.19	1.22	0.39	38.89	58.25	NS
Absolute control	31.6	15.4	14.3	6.7	756.1	4062.3	15.6
Rest	43.1	27.8	25.2	8.3	890.4	4164.8	17.5
SED +	4.06	1.28	1.25	0.17	1.20	63.92	0.47
LSD (P=0.05)	8.20	2.58	2.52	0.34	2.42	129.11	0.94

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Table 47. Residual effect of nitrogen sources, sulphur and boron levels on yield attributes, yields and harvest index of succeeding mungbean in sunflower-mungbean cropping system (2006)

Treatments	2006						
	Plant height (cm)	Number of branches/plant	Number of pods/plant	Number of grains/pod	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
Nitrogen sources							
PU	38.0	24.8	22.9	7.5	812.1	4003.9	16.8
CAN	44.3	28.7	24.6	8.1	916.3	4185.2	17.9
SEM ±	0.58	0.30	0.31	0.10	11.05	25.91	0.28
LSD (P=0.05)	1.60	0.84	0.85	NS	30.60	NS	0.75
Sulphur levels (kg/ha)							
0	39.5	24.2	20.1	7.1	769.3	3985.5	16.3
25	43.5	26.5	23.9	8.1	886.4	4012.5	18.0
50	46.7	29.5	27.2	8.3	937.5	4285.6	17.8
SEM ±	0.78	0.40	0.35	0.11	13.04	41.11	0.48
LSD (P=0.05)	2.15	1.10	0.96	0.30	36.12	113.87	NS
Boron levels (kg/ha)							
0	40.1	23.1	20.2	6.7	785.1	4018.6	16.4
0.75	42.8	27.0	24.8	7.9	886.3	4045.9	17.9
1.50	46.9	30.0	26.2	8.9	921.4	4219.2	17.9
SEM ±	0.78	0.40	0.35	0.11	13.04	41.11	0.48
LSD (P=0.05)	2.15	1.10	0.96	0.30	36.12	113.87	NS
Absolute control							
Rest	30.1	14.2	14.0	7.2	762.1	4001.5	15.99
SED ±	43.2	26.7	23.7	7.8	864.3	4094.5	17.41
SEM ±	3.96	1.15	1.20	0.15	14.08	51.51	1.00
LSD (P=0.05)	7.99	2.32	2.42	0.30	28.44	104.05	2.00

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

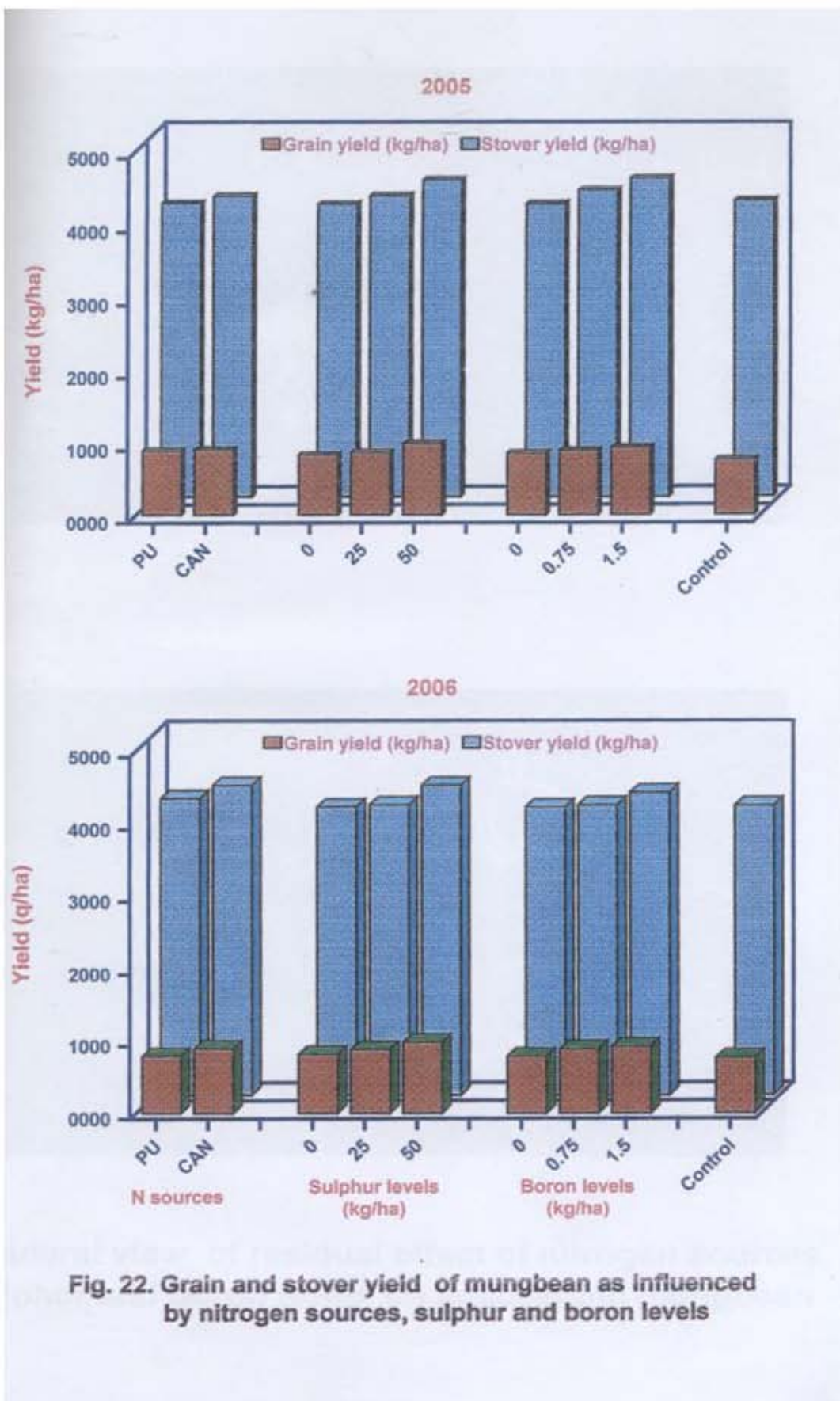


Fig. 22. Grain and stover yield of mungbean as influenced by nitrogen sources, sulphur and boron levels



A general view of residual effect of nitrogen sources, sulphur and boron levels on succeeding mungbean

4.2.1.1 Plant height

Plant height of mungbean was recorded at the time of the harvest and is presented in Table 46 and 47. A careful observation revealed that higher plant height data were recorded during the first year compared to second year. A significantly more plant height was noticed when N was supplied to sunflower through CAN during both the years. Application of S was again an important practice for sunflower as the residual effect on mungbean was clear as it produced a significantly taller mungbean plants during both the years of the study. About 20% increment was seen during both the years. Likewise, B also had a significant residual effect and was able to increase the plant height but the increment was lower than S. Even then, all the fertilizer treatments were far more superior than absolute control during 2005 and 2006.

4.2.1.2 Number of branches per plant

Data on number of branches were recorded at the time of harvest and are presented in Table 46 and 47. In both the years, CAN produced significantly more number of branches per plant. The difference due to S application was also significant. In 2005, S application @ 50 kg/ha produced about 5 branches more/plant and in 2006 also the data remained the same. B on the other hand was proved more significant in increasing the number of branches/plant. For 2005, the increment was almost 5 branches/plant and in 2006 about 6 branches/plant with B @ 1.5 kg/ha. Control here also, produced minimum number of branches/plant during both the years of the trial.

4.2.1.3 Number of pods/plant

The data on number of pods/plant as influenced by N source, S and B levels is shown in Table 46 and 47. N application through CAN produced higher number of pods per plant during both the years of the study. Application of S also enhanced significant number of pods produced per plant and the increment was 18% with 25 kg S/ha and was about 14% with 50 kg S/ha during 2005. The values were almost the same for the year 2006. Likewise B produced significantly higher number of pods/plant but the numbers were higher during 2006 than 2005.

4.2.1.4 Number of grains/pod

Yet another yield attribute of mungbean i.e. number of grains/pod was recorded and is presented in Table 46 and 47. Number of grains/pod was higher during the first year than the second year. N sources whether urea or CAN was not able to leave an impact on the observation of number of grains/pod during any of the year. S application in sunflower had a significant residual effect on succeeding mungbean. It enhanced number of grains/pod but significantly only up to 25 kg S/ha, beyond which no further significant increase was observed during any of the years. B on the other hand was very effective even at the higher doses of 1.5 kg/ha which produced significantly higher number of grains/pod during both the years of the study. Control still could not prove superior to any of the treatment and recorded minimum number of grains/pod.

4.2.2 Yield and harvest index (HI)

Data pertaining to grain yield, stover yield and harvest index were recorded and are given in Table 46 and 47 and Fig. 22.

4.2.1.1. Grain yield

Grain yield of mungbean was recorded higher during the first year. All the treatments were superior than control during both 2005 and 2006. In 2005, urea and CAN were equally effective in enhancing the grain yield and both were statistically at par with each other. But in 2006, CAN produced significantly higher grain yield than urea.

S application was almost equally effective for both the years. In 2005, a 4.8% increase was seen in grain yield due to application of 25 kg S/ha and about 13.9% increase due to 50 kg S/ha was recorded. While in 2006, the data were 14.9% and 5.5%, respectively. Likewise B also had a positive correlation with grain yield. The increment was almost same for both the years while the per cent increase was higher during the second year.

4.2.2.2 Stover yield

Data presented in Table 46 and 47 and Fig. 22 revealed the effect of various treatments on stover yield of succeeding mungbean. Stover yield was higher for the

second year than 2005. N source could not make any significant difference in stover yield during any of the years of the study. While S was effective at both 25 and 50 kg S/ha. The response was higher with the first dose than the second dose during 2005, while the pattern was reversed for 2006. B also brought a significant change in stover yield of succeeding mungbean during both the years of the study, the stover yield superior than absolute control in both the years of experimentation.

4.2.2.3 Harvest index (HI)

Data presented in Table 46 and 47 revealed that HI followed the same pattern as that of grain yield. The N sources significantly enhanced the HI in 2006 only. CAN produced significantly higher HI in 2006. S application was able to cause a significant change in 2005 while it was non-significant to increase HI in 2006 for both the doses. Whereas B failed to cause any significant effect on HI in 2005 and 2006 All the treatment results were quite superior than control irrespective of the growing season of the crop.

4.2.3 Nutrient concentration of mungbean

After the harvest of the succeeding mungbean crop, various nutrients like N, P, K, S and B were estimated in both grain and stover of mungbean and the data are presented in Table 48 and 49.

4.2.3.1 N concentration

N concentration was higher in grain than stover as is clear from Table 48 and 49 during both the years of the study. Nutrient application resulted in higher N concentration during both the years, thus all the treatments were significantly superior than control. N application through different sources were failed to cause a significant effect on N concentration either in grain or stover in 2005 and the case was opposite for 2006. S application had a positive effect on N concentration both in grain and stover. During 2005, N concentration in grain increased up to 0.22% and for stover the enhancement was 0.36%. Following the similar trend in 2006, grain accumulated 0.20% more N and 0.26% more N in stover. Residual effect of B application also enhanced the N concentration of both grain and stover while the increase was more for S.

4.2.3.2 P concentration

Table 48. Residual effect of nitrogen sources, sulphur and boron levels on nutrient concentration in succeeding mungbean crop in sunflower-mungbean cropping system (2005)

Treatments	2005											
	N concentration (%)		P concentration (%)		K concentration (%)		S concentration (%)		B concentration (mg/kg DM)			
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover		
Nitrogen sources												
PU	3.29	2.13	1.33	1.00	1.24	2.05	0.24	0.18	25.40	23.25		
CAN	3.37	2.22	1.42	1.08	1.29	2.14	0.25	0.18	25.47	23.67		
SEM +	0.03	0.02	0.01	0.01	0.02	0.03	0.02	0.002	0.21	0.19		
LSD (P=0.05)	NS	NS	NS	0.04	NS	NS	NS	NS	NS	NS		
Sulphur levels (kg/ha)												
0	3.16	2.01	1.31	0.96	1.17	1.95	0.23	0.17	24.29	22.79		
25	3.36	2.15	1.35	1.03	1.22	2.05	0.25	0.18	25.20	23.21		
50	3.47	2.37	1.42	1.13	1.43	2.27	0.25	0.20	26.66	24.38		
SEM +	0.03	0.03	0.02	0.01	0.02	0.02	0.002	0.002	0.26	0.23		
LSD (P=0.05)	0.10	0.08	0.05	0.03	0.06	0.06	0.008	0.006	0.73	0.66		
Boron levels (kg/ha)												
0	3.11	2.04	1.25	0.96	1.12	1.93	0.23	0.16	25.00	23.00		
0.75	3.40	2.21	1.37	1.05	1.27	2.10	0.25	0.18	25.41	23.58		
1.50	3.49	2.29	1.49	1.12	1.41	2.25	0.25	0.19	25.85	23.78		
SEM +	0.03	0.03	0.02	0.01	0.02	0.02	0.002	0.002	0.26	0.23		
LSD (P=0.05)	0.10	0.08	0.05	0.03	0.06	0.06	0.008	0.006	0.73	0.66		
Absolute control	2.52	1.68	1.03	0.80	0.87	1.56	0.19	0.12	23.71	21.72		
Rest	3.33	2.17	1.37	1.04	1.26	2.09	0.24	0.18	25.42	23.46		
SED +	0.09	0.07	0.05	0.03	0.03	0.05	0.04	0.005	0.64	0.59		
LSD (P=0.05)	0.18	0.14	0.10	0.06	0.06	0.10	0.08	0.010	1.29	1.19		

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Table 49. Residual effect of nitrogen sources, sulphur and boron levels on nutrient concentration in succeeding mungbean crop in sunflower-mungbean cropping system (2006)

Treatments	2006											
	N concentration (%)		P concentration (%)		K concentration (%)		S concentration (%)		B concentration (mg/kg DM)			
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover		
Nitrogen sources												
PU	3.20	2.10	1.19	0.98	1.20	1.90	0.29	0.19	26.85	24.85		
CAN	3.31	2.21	1.31	1.04	1.26	1.92	0.30	0.23	27.80	25.83		
SEM +	0.01	0.02	0.03	0.01	0.03	0.02	0.02	0.03	0.41	0.52		
LSD (P=0.05)	0.03	0.06	0.09	0.03	NS	NS	NS	NS	NS	NS		
Sulphur levels (kg/ha)												
0	3.15	2.01	1.12	0.98	1.16	1.76	0.20	0.15	25.05	23.00		
25	3.27	2.17	1.26	1.09	1.23	1.92	0.28	0.21	27.63	24.96		
50	3.35	2.27	1.37	1.17	1.31	2.04	0.37	0.27	29.29	28.07		
SEM +	0.02	0.03	0.04	0.02	0.05	0.03	0.04	0.03	0.51	1.03		
LSD (P=0.05)	0.06	0.09	0.12	0.05	0.14	0.10	0.12	0.10	1.47	2.85		
Boron levels (kg/ha)												
0	3.16	2.02	1.18	0.96	1.11	1.73	0.25	0.17	24.09	22.65		
0.75	3.25	2.17	1.27	1.09	1.23	1.93	0.29	0.21	27.81	24.86		
1.50	3.34	2.26	1.32	1.17	1.36	2.07	0.32	0.27	30.06	28.51		
SEM +	0.02	0.03	0.04	0.02	0.05	0.03	0.04	0.03	0.51	1.03		
LSD (P=0.05)	0.06	0.09	0.12	0.05	0.15	0.10	0.12	0.10	1.47	2.85		
Absolute control	2.48	1.87	1.02	0.82	0.92	1.66	0.20	0.14	22.72	20.61		
Rest	3.25	2.15	1.25	1.08	1.23	1.91	0.28	0.21	27.32	25.34		
SED +	0.03	0.04	0.06	0.06	0.06	0.08	0.06	0.05	0.59	1.50		
LSD (P=0.05)	0.06	0.08	0.12	0.12	0.12	0.16	0.12	0.10	1.19	3.03		

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Average data on total P concentration of mungbean in grain and stover were recorded and are presented in Table 48 and 49. A careful observation of data revealed that grain has higher P concentration than stover but the values were numerically higher during the first year. In 2005, residual effect of urea and CAN remained statistically at par in grain as far as P concentration is concerned, while in stover, CAN produced stover with high P concentration which was significantly superior than urea, but in 2006, CAN performed better. The various levels of S and B had a positive correlation with P concentration in different plant parts of succeeding mungbean. During both the years, S application enhanced the P concentration in grain from 0.11 – 0.12% while B increased the P concentration from 0.08 – 0.14% during 2005 and 2006, respectively. All the sources and level of nutrient were found to be significantly superior than absolute control.

4.2.3.3 K concentration

The data pertaining to K concentration in grain and stover were analyzed and are presented in Table 48 and 49. The K concentration was observed higher in stover during both the years. Although no K containing fertilizer was added, still other nutrients had a positive significant impact on the K concentration of the plant. In 2005, N sources could not make any significant difference either in grain or stover and the same trend was seen during 2006 as well. S application was important to enhance the K concentration of both grain and stover. In 2005, a 22% increase in K concentration of grain was observed due to S application @ 50 kg S/ha while the stover experienced a 16% increment. While for 2006, the respective changes were 12 and 15% for grain and stover. The increment for K concentration was slightly more with B application @ 1.5 kg B/ha during both the years, where all the treatments were superior than absolute control.

4.2.3.4 S concentration

Effect of various preceding treatments on S concentration in succeeding mungbean crop was recorded and is given in Table 48 and 49. A higher amount of S concentration was noticed in grain during both the years. Like other treatments source of N could not make much difference and the values for urea and CAN were statistically at par with each other. The S application had a positive linear relationship

with N concentration during both the years while the values were significantly higher in the second year. The per cent increment in S concentration in grain was only 13% in 2005 while about 40% during 2006. S concentration in stover followed the same trend. B application also enhanced S concentration in grain and stover during both the years but the increase was lower than S although higher than absolute control.

4.2.3.5 B concentration

The application of B in the preceding sunflower crop had a marked influence on B concentration in succeeding mungbean crop. B concentration in grain was slightly higher than in stover during both 2005 and 2006. As per the set trend, the N application could not bring any significant change during any of the seasons. In 2005, S application had a marked influence on B concentration while in 2006, the difference was rather more clear than the previous year. A corresponding increase in B concentration was seen due to application of B. A linear change was observed during both the years but the increase was very sharp in 2006. All the treatments resulted better, statistically than absolute control and the conclusion was confirmed by the data of the second year also.

4.2.4 Total nutrient uptake by mungbean

4.2.4.1 N uptake

The data related to N uptake in grain, stover and total uptake is shown in Table 50 and 51 and Fig. 23. A higher uptake by succeeding mungbean crop was noticed during both the years, but the amount was higher during the first year than 2006. In 2005, total uptake as well as grain and stover uptake was significantly influenced by N source as CAN resulted in higher uptake than urea. A similar pattern could be seen in the second year also. S application at both doses significantly influenced the uptake whereas the N uptake increment was more at the second dose of S application @ 50 kg/ha. A different pattern was noticed due to B application where more sharp response was seen at 0.75 kg/ha. All the treatments were of course, superior than absolute control during both the years of cropping season.

4.2.4.2 P uptake

Table 50. Residual effect of nitrogen sources, sulphur and boron levels on total nutrient uptake by succeeding mungbean crop in sunflower-mungbean cropping system (2005)

Treatments	2005																	
	N (kg/ha)			P (kg/ha)			K (kg/ha)			S (kg/ha)			B (g/ha)					
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total			
Nitrogen sources																		
PU	29.06	87.75	116.81	11.74	41.17	52.91	11.00	84.42	95.42	2.10	7.41	9.51	22.43	95.73	118.16			
CAN	30.24	93.45	123.69	12.75	45.49	58.24	11.62	90.12	101.74	2.23	7.58	9.81	22.85	99.69	122.54			
SEm +	0.21	1.23	1.62	1.19	1.31	1.62	0.27	5.07	3.09	0.04	0.10	0.11	0.46	3.11	4.17			
LSD (P=0.05)	0.58	3.42	4.48	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
Sulphur levels (kg/ha)																		
0	26.06	80.46	106.52	11.08	38.47	49.55	9.55	78.35	87.90	1.89	6.67	8.56	20.68	91.43	111.44			
25	28.80	88.57	117.37	11.86	42.47	54.33	10.40	84.74	95.14	2.15	7.28	9.43	22.34	95.81	117.48			
50	34.11	102.78	136.89	13.79	49.05	62.84	13.98	98.73	112.71	2.46	8.54	11.00	24.91	105.91	132.15			
SEm +	0.50	1.51	3.70	1.23	1.62	2.88	0.29	6.32	4.92	0.05	0.12	0.18	1.07	3.49	3.03			
LSD (P=0.05)	1.40	4.19	10.27	NS	4.48	7.97	0.74	17.50	13.62	0.15	0.33	0.47	2.97	9.69	8.94			
Boron levels (kg/ha)																		
0	26.37	81.01	107.38	10.56	38.12	47.77	9.52	76.86	86.38	1.95	6.49	8.44	21.30	92.14	113.44			
0.75	30.16	91.92	122.08	12.17	43.61	54.78	11.26	87.57	98.83	2.21	7.63	9.84	22.54	98.43	120.97			
1.50	32.40	98.89	131.29	13.93	48.26	61.19	13.16	97.39	110.55	2.33	8.35	10.68	24.08	102.56	126.64			
SEm +	0.50	1.51	3.70	1.23	1.62	2.88	0.29	6.32	4.92	0.05	0.12	0.18	1.07	3.49	3.03			
LSD (P=0.05)	1.40	4.19	10.27	NS	4.48	7.97	0.74	17.50	13.62	0.15	0.33	0.47	2.97	9.69	8.94			
Absolute control	19.05	70.28	82.37	7.52	32.54	40.54	6.52	63.28	68.99	1.44	4.82	6.34	18.09	88.25	106.34			
Rest	29.65	90.60	120.25	12.24	43.33	55.57	11.31	87.27	98.58	2.16	7.49	9.66	22.64	97.71	120.35			
SEd +	1.27	3.80	10.11	0.57	1.34	3.58	0.37	8.29	5.23	0.06	0.21	0.30	1.25	2.25	5.12			
LSD (P=0.05)	2.56	7.67	20.42	1.15	2.70	7.23	0.74	16.74	10.56	0.12	0.42	0.60	2.51	4.54	10.34			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

sunflower-mungbean cropping system (2006)

Treatments	2006																	
	N (kg/ha)			P (kg/ha)			K (kg/ha)			S (kg/ha)			B (g/ha)					
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total			
Nitrogen sources																		
PU	25.98	84.08	110.06	9.72	43.36	53.08	9.81	77.06	86.87	2.35	7.64	9.99	22.26	92.89	115.15			
CAN	30.33	92.49	122.82	12.06	45.24	57.30	11.61	79.35	90.96	2.74	9.66	12.40	25.98	101.51	127.48			
SEM +	2.21	1.17	1.75	1.12	0.13	2.06	1.06	1.36	2.11	0.09	0.48	0.54	1.21	4.14	2.37			
LSD (P=0.05)	NS	3.24	4.84	NS	NS	NS	NS	NS	NS	0.24	1.32	1.49	NS	NS	6.56			
Sulphur levels (kg/ha)																		
0	24.16	80.23	104.39	8.37	39.05	47.66	9.44	70.14	79.58	1.82	5.97	7.79	19.50	85.01	104.51			
25	28.93	87.20	116.13	11.67	43.73	54.92	10.65	77.04	87.69	2.54	8.42	10.96	24.91	93.54	118.36			
50	31.36	97.41	128.77	12.64	50.14	63.02	12.04	87.42	99.46	3.26	11.57	14.83	27.97	113.13	141.10			
SEM +	2.21	2.58	2.34	2.88	0.62	2.58	1.27	2.14	2.62	0.41	0.57	0.59	1.58	4.54	3.71			
LSD (P=0.05)	6.12	7.14	6.48	NS	1.74	7.14	3.53	6.93	7.26	1.14	1.59	1.64	4.38	12.57	10.27			
Boron levels (kg/ha)																		
0	25.09	81.35	106.19	9.59	38.86	48.12	8.71	69.41	78.12	2.01	6.58	8.59	19.29	84.25	103.54			
0.75	29.08	87.97	116.82	11.58	44.39	55.64	10.90	77.97	88.87	2.62	8.24	10.86	25.02	93.81	118.83			
1.50	30.33	95.53	126.33	11.49	49.65	61.81	12.53	87.22	99.75	2.99	11.14	14.13	28.07	113.51	141.58			
SEM +	2.21	2.58	2.34	0.88	0.62	2.58	1.27	2.14	2.62	0.41	0.57	0.59	1.58	4.54	3.71			
LSD (P=0.05)	6.12	7.14	6.48	NS	1.74	7.14	3.53	6.93	7.26	1.14	1.59	1.64	4.38	12.57	10.27			
Absolute control	18.90	78.89	97.42	7.41	34.52	41.94	7.04	70.08	77.14	1.54	5.91	7.84	17.33	86.94	104.29			
Rest	28.15	88.28	116.44	10.89	44.30	55.19	10.71	78.20	88.91	2.54	8.65	11.19	24.12	97.19	121.13			
SED +	3.11	3.51	3.80	1.23	0.81	3.27	2.15	2.58	2.82	0.61	1.04	1.09	2.61	4.80	4.70			
LSD (P=0.05)	6.28	7.07	7.67	2.48	1.78	6.60	4.34	5.21	5.69	1.23	2.08	2.18	5.27	9.69	9.49			

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

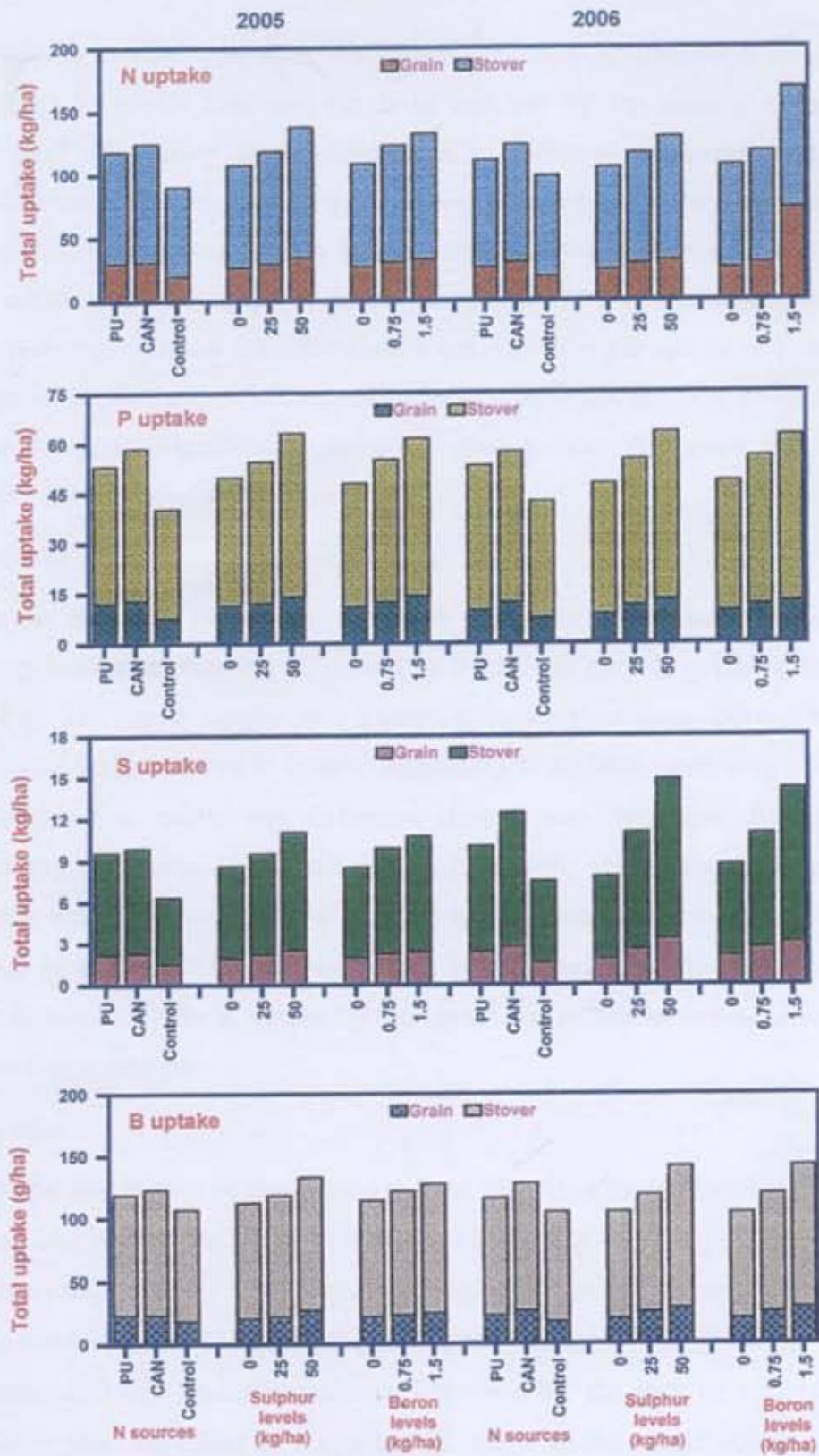


Fig. 23. Total nutrient uptake by mungbean as influenced by nitrogen sources, sulphur and boron levels

The results pertaining to total P uptake by the crop is mentioned in Table 50 and 51 and Fig. 23 which followed the trend set out by the average trend of P concentration and dry matter accumulation due to different treatments applied to preceding sunflower crop and residual yield in succeeding mungbean crop. Here also the values were higher for the stover. A significant difference in N sources was visible during 2005 which was diluted due to some reasons in 2006. S application was also non-significant during both the years for grain P uptake while the uptake of P in stover due to various level of S and B treatments became significant in 2006. B application enhanced the P uptake significantly in stover during both the years and all the treatments were superior to absolute control.

4.2.4.3 K uptake

Data on effect of N sources, S and B levels on K uptake by succeeding mungbean crop due to fertilization of preceding sunflower crop is given in Table 50 and 51 and Fig. 23. The K uptake was higher in stover than grain during both the years. It followed the pattern of P uptake. Regarding N sources, both urea and CAN were non-significant to create any difference during both 2005 and 2006. The S application at any dose was significant during 2005 with almost steady increase in uptake by grain and stover at 25 and 50 kg S/ha, while similar trend was seen in 2006. In 2006, the B @ 0.75 kg S/ha was significant but remained statistically at par with 1.50 kg B/ha in enhancing the K uptake by both grain and stover as well as total uptake also by succeeding mungbean.

4.2.4.4 S uptake

S uptake was higher in the second year as shown in the Table 50 and 51 and Fig. 23. The uptake was higher in stover than in grain during both the years. N sources, although were unable to make any residual difference but an ample residual impact of S application was observed. During 2005, an increase up to 30% in grain and 28% in stover was noticed. B also caused significant difference but the pace of increment in S uptake was lower than the effect by S application, while all the treatments were higher and significantly superior than absolute control in all treatments and plant parts.

4.2.4.5 B uptake

B uptake by mungbean in grain and stover along with total uptake is given in Table 50 and 51 and Fig. 23. The perusal of the data revealed that the B uptake was higher by stover than in grain during both the years. Numerically, the B uptake was higher during the second year than the first year. Like B concentration, the uptake was also not influenced significantly by N source. Urea and CAN were equally efficient in enhancing B uptake by grain and stover during both the years with S fertilization of preceding sunflower crop, a significant effect was seen in B uptake by succeeding crop of mungbean. S application @ 25 kg/ha had a good response while sharper response was observed during the second dose of 50 kg S/ha during both the years of the study. B application had a linear positive residual effect on B uptake during both the years. In 2005, a 21% increase in B uptake by grain and 10% by stover was noticed and the statistics for 2006 were 45% and 34%, respectively for grain and stover. Following the usual trend, the uptake of B at different doses of S and B by different components was significantly superior than control during both the years of experimentation.

4.2.5. Available nutrient status of soil after harvest of sunflower-mungbean cropping system

The effect of N sources, S and B levels on available nutrient status of the soil in terms of available N, P, K, S and B were estimated and tabulated in Table 52.

4.2.5.1 Available N

The average data on status of available N in soil indicated that the values were higher in the second year. N sources were not able to make any significant difference and both remained statistically at par with each other. S application increased the available N during both the years but the increase was higher during the second year. Similarly B treatment also left a reasonable amount of available N in the soil. Residual available N was almost 12 kg higher in 2005 and about 10 kg higher in 2006 than absolute control which left minimum available N during both the years.

4.2.5.2 Available P

Data on available P revealed that there was no significant difference in available P among various treatments including control in 2005. In 2006, all the treatments were superior over only control and rest all the levels remained statistically at par with each other during both the cropping seasons.

Treatments	Soil depth (0-20 cm)														
	2005							2006							
	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	B (mg/kg)	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	B (mg/kg)	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	B (mg/kg)
Nitrogen sources															
PU	142.16	12.47	210.51	25.10	1.65	156.21	11.69	198.97	27.97	1.73					
CAN	147.59	12.55	212.79	26.16	1.67	158.29	11.95	201.25	29.55	1.78					
SEm +	2.11	0.32	1.01	1.67	0.03	1.36	0.52	1.89	1.05	0.09					
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS					
Sulphur levels (kg/ha)															
0	139.94	12.13	210.74	21.57	1.51	149.62	12.17	203.10	27.93	1.69					
25	145.07	12.43	211.48	25.55	1.71	157.15	11.87	201.17	35.10	1.75					
50	149.62	12.99	212.73	29.78	1.78	164.99	11.52	196.06	35.89	1.84					
SEm +	2.11	0.97	1.48	2.49	0.08	4.64	0.67	3.82	1.22	0.03					
LSD (P=0.05)	5.84	NS	NS	6.89	0.23	7.32	NS	NS	3.69	0.09					
Boron levels (kg/ha)															
0	139.57	12.14	210.43	24.63	1.39	152.15	12.33	203.11	23.71	1.64					
0.75	145.41	12.63	211.99	25.69	1.62	157.58	11.99	200.72	25.62	1.73					
1.50	149.45	12.77	211.62	26.59	1.99	162.02	11.22	196.51	27.89	1.93					
SEm +	2.11	0.97	1.48	2.49	0.08	4.64	0.67	3.82	1.22	0.03					
LSD (P=0.05)	5.84	NS	NS	NS	0.23	7.32	NS	NS	NS	0.09					
Absolute control	130.27	11.11	210.11	19.11	1.24	146.51	11.12	212.81	23.72	1.37					
Rest	144.87	12.51	211.65	25.63	1.66	157.25	11.85	200.11	25.74	1.76					
SEd +	4.99	1.02	2.31	2.62	0.09	5.06	0.45	5.17	1.36	0.11					
LSD (P=0.05)	10.07	NS	NS	NS	0.18	10.10	0.90	NS	2.74	0.22					

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

4.2.5.3 Available K

The data in the Table 52 revealed that like P, available K also showed the same results. All treatments including control were at par with each other during both the years of experimentation.

4.2.5.4 Available S

Since S was applied to preceding sunflower crop in sunflower-mungbean cropping system, the residual effect was seen after the harvest of the succeeding mungbean, which is shown in Table 52. N sources had no significant effect on available S concentration in soils.

S application enhanced the available S status by 8-10 kg in 2005 and 8-9 kg in 2006. B application through different levels failed to cause any effect on available S status of soil during any of the year. Although, all the treatments were statistically superior than absolute control.

4.2.5.5 Available B

Data pertaining to available B status of soil during 2005 and 2006 is presented in Table 52. A careful perusal of the data revealed that N sources i.e. urea and CAN were equally effective in enhancing the available B status of soil during 2005 and 2006. Application of S had a profound effect in enhancing the B status in soil. During 2005, it resulted in 0.27 mg/kg increase while in 2006 the difference was 0.15 mg/kg. Due to B application at 0.75 kg B/ha, the available B increased by 0.23 mg/kg and by 1.5 kg B/ha by 0.35 mg/kg during 2005, while data was about 0.09 mg/kg and 0.20 mg/kg for 2006. Above all, different treatments were superior over absolute control during both the years of the experimentation.

4.2.6. Monetary returns from mungbean

Monetary returns in terms of net returns and B: C ratio of mungbean is presented in Table 53. During both the years of the study, S application @ 50 Kg/ha produced maximum net returns and B: C ratio, although the values were higher for the year 2005 than 2006.

4.2.7. Monetary returns from the sunflower-mungbean cropping system

If we study the economic analysis of the system as a whole, S application @ 50 kg/ha proved to be the best in terms of net returns and B: C ratio. During both the years of the study, B: C ratio obtained for S application @ 50 kg/ha was 2.38 and 2.20 respectively. The next best results were obtained by B application @ 1.5 kg/ha.

Table 53. Effect of nitrogen sources, sulphur and boron levels on cost of cultivation, gross returns, net returns and benefit:cost ratio of succeeding mungbean crop

Treatments	2005				2006			
	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
Nitrogen sources								
PU	7165.5	23842.9	16677.4	2.32	7245.3	22247.8	15002.5	2.07
CAN	7165.5	24266.3	17100.8	2.38	7245.3	24603.8	17358.5	2.39
SEM ±	-	246.5	212.4	0.03	-	305.7	246.2	0.02
LSD (P=0.05)	-	NS	NS	NS	-	846.7	681.9	0.05
Sulphur levels (kg/ha)								
0	7165.5	22521.6	15356.1	2.14	7245.3	21364.2	14118.9	1.94
25	7165.5	23419.7	16254.2	2.26	7245.3	23746.7	16501.4	2.27
50	7165.5	26225.7	19060.2	2.65	7245.3	25178.4	17933.1	2.47
SEM ±	-	259.4	236.7	0.04	-	336.8	293.3	0.03
LSD (P=0.05)	-	718.5	236.7	0.11	-	932.9	812.4	0.08
Boron levels (kg/ha)								
0	7165.5	22987.4	15821.9	2.20	7245.3	21729.9	14484.6	1.99
0.75	7165.5	24012.2	15821.9	2.35	7245.3	23794.8	16549.5	2.28
1.5	7165.5	25169.4	18003.9	2.51	7245.3	24756.8	17511.5	2.41
SEM ±	-	259.4	236.7	0.04	-	336.8	293.3	0.03
LSD (P=0.05)	-	718.5	655.6	0.11	-	932.9	812.4	0.08
Absolute control								
Absolute control	7165.5	21215.9	14050.4	1.96	7245.3	21244.2	13998.9	1.93
Rest	7165.5	24055.7	16890.2	2.35	7245.3	23427.7	16182.4	2.23
SEM ±	-	283.3	249.4	0.05	-	347.5	312.6	0.04
LSD (P=0.05)	-	572.2	503.7	0.10	-	701.9	631.4	0.08

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

Table 54. Effect of nitrogen sources, sulphur and boron levels on cost of cultivation, gross returns, net returns and benefit:cost ratio of sunflower-mungbean cropping system

Treatments	2005				2006			
	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
Nitrogen sources								
PU	18099.2	60031.8	41932.6	2.31	18290.1	57056.7	38766.6	2.11
CAN	20495.3	61373.2	40877.9	1.99	20582.3	60490.0	39907.7	1.93
SEM +	248.4	399.1	297.5	0.03	259.6	328.5	312.7	0.02
LSD (P=0.05)	688.0	1105.5	824.0	0.08	719.0	909.9	866.1	0.04
Sulphur levels (kg/ha)								
0	19078.7	56886.3	37807.6	1.98	19143.4	54317.4	35174.0	1.83
25	19383.7	59377.9	39994.2	2.06	19448.4	58761.9	39313.5	2.02
50	19429.5	65836.5	46397.0	2.38	19716.8	63252.8	43536.0	2.20
SEM +	286.5	426.7	317.9	0.05	274.5	411.7	328.7	0.03
LSD (P=0.05)	NS	1181.9	880.5	0.13	NS	1140.4	910.4	0.08
Boron levels (kg/ha)								
0	18688.7	54368.3	35679.6	1.90	18753.4	51732.7	32979.3	1.75
0.75	19383.7	62871.2	43487.5	2.24	19528.4	61700.9	42172.5	2.15
1.5	19819.5	64874.1	45054.6	2.27	20106.6	62890.7	42784.1	2.12
SEM +	286.5	426.7	317.9	0.05	274.5	411.7	328.7	0.03
LSD (P=0.05)	793.6	1181.9	880.5	0.13	760.3	1140.4	910.4	0.08
Absolute control	16137.0	43334.3	27197.3	1.68	16201.8	43143.0	26941.2	1.66
Rest	19297.3	60703.6	41406.3	2.14	19462.8	58775.3	39312.5	2.01
SED +	359.1	512.8	410.8	0.06	287.5	496.2	349.6	0.05
LSD (P=0.05)	725.5	1035.8	829.8	0.12	580.7	1002.3	706.1	0.10

PU = Prilled urea; CAN = Calcium ammonium nitrate; DAS = Days after sowing

DISCUSSION

The salient research findings obtained from the investigation conducted to assess the effect of N sources, S and B levels on sunflower and its residual effect on succeeding mungbean, are discussed in this chapter in the light of scientific data generated by other workers and also by establishing a cause and effect relationship between the observations.

5.1 Weather conditions and crop growth

The present investigation was carried out in spring and *kharif* seasons, due to which the study of the weather parameters has paramount importance. A careful study of the meteorological data presented in Table 2 (a) and 2 (b) and depicted in Fig. 1a and 1b revealed that the weather parameters played a crucial role in influencing growth, yield and yield attributes of sunflower and succeeding mungbean. A critical appraisal of weather data for two years revealed distinct variation in temperature, rainfall and sunshine hours etc. in two cropping seasons. In two years study, sunflower crop was sown on 25 February and 15 February, respectively. Although sunflower crop is less influenced by temperature and sunshine hours, still a wide variation can affect the crop growth and productivity reasonably. The advancement in sowing by 10 days in spring season of 2006, showed tremendous influence on growth, yield and yield attributes of sunflower. Low temperature during germination and plant establishment stages in second year resulted in slow growth. Ghulam (2006) also reported that the maximum germination rate was observed at 20 and 25°C in the entire hybrid. Due to high maximum and minimum temperature and more sunshine hours in first year were observed to be more congenial for initial crop growth. This effect is evident by the recorded data on initial growth of the crop.

Due to difference in planting dates, the significant differences were found in both the cropping seasons for heat unit accumulation. The crop consuming the

maximum heat units gave the maximum yield. Since the temperature became very high during the flowering stage and the harvest stage, the growth period reduced in the second year and the crop was harvested earlier. At harvest stage, higher temperature was recorded in 2006 than 2005. This caused significant difference for all the growth and yield attributes during both the seasons. Brown and Plan (2006) also reported that crop yield is one of the most sensitive economic trend to higher temperature. Crop like sunflower in India is grown at or near their thermal optimum, making them vulnerable to any rise in temperature. Higher temperature can reduce or even halt photosynthesis, prevent pollination and ultimately lead to crop dehydration.

Sunflower requires warm weather from seedling stage to flowering stage and warm and sunny days during flowering to maturity, which was a favourable reason for higher yield in 2005. Low yield in 2006 could be due to high humidity accompanied with cloudy weather and rainfall at the time of flowering, which resulted in poor seed set. During critical crop growth phases in the development of a crop, such as near flowering, the transgression of high temperature thresholds can reduce the number of seeds or grain that subsequently contribute to crop yield. This impact is independent of seasonal mean temperature. A few days of high temperature are sufficient to have a potentially large impact on yield, as also reported by Challinor (2004).

During 2005, the mean temperature remained 20-28°C during grand growth phase, which is considered ideal for growth and development. This resulted in higher biomass during 2005 whereas in 2006, higher temperature at harvest stage suppressed the development of sunflower crop during reproductive phase and resulted into lower values of yield attributes. Dipenbrock (1988) also found that night temperatures below 10°C and day temperature above 35°C adversely affect the growth and development e.g. seed setting and oil content, respectively.

Another reason for higher oil content during 2005 was the optimum day temperature, which produced maximum leaf, stem and root dry matter under 30°C day temperature regardless of night temperature. Oil yield can be estimated by determining dry matter accumulation of all ground parts. This close relationship between oil yield and flowering did not occur in 2006 because of extremes of temperature, since the

higher temperature was detrimental to dry matter reserves in the plant. The findings were in line with the study of Duriyaprapan^{et al}(1986).

A good correlation is obtained between oil quality and temperature during the post-flowering period. A good quality oil was produced in terms of linoleic and oleic acid in 2006 because oil quality improves with timely sowing in association with lower temperature and a higher linoleic acid was recovered. Similar results were observed by Keefer *et al.* (2005).

Water also affects growth, yield and oil concentration and its composition. Timely rainfall in 2005, which was favourable for growth and development of sunflower. There was no water deficit from seedling to the bud-flowering stage in 2005 but in 2006, aberrant rainfall occurred at flowering stage, while crop faced a moisture stress during flowering to physiological maturity period. Rodriguez (2002) also reported the sunflower may experience low oil concentration due to short seed filling stage, caused by water stress and high temperature during this period.

Seasonal effect on succeeding mungbean was also observed in both the years of the study. In 2005, the distribution and total rainfall was much above the normal (Fig. 1a and 1b) whereas in 2006, not only arrival of monsoon was delayed but total rainfall was also much below normal. The succeeding mungbean crop was sown late in 2006. In this season dryness in microclimatic could not be compensated with irrigation, hence yield of succeeding mungbean was low.

5.2 Effect of N sources, S and B levels on sunflower

5.2.1 Growth characters

All the growth parameters were significantly influenced by application of various fertilizer treatments in two years of the study (Table 1-14 and Fig. 3-7).

5.2.1.1 Plant height

Application of various fertilizer treatments resulted in higher plant height in both the years of the study than control due to early and higher availability of plant nutrients in a soluble and easily absorbable form. The higher rate of growth was experienced at 25-50 DAS and 50-75 DAS due to availability of more nutrients after mineralization of the applied forms. At harvesting, the rate of growth declined due to

diversion of nutrients towards the reproductive sinks. The lower height of the plants were noticed during the second year because of early sowing where plants experienced low temperature for growth.

A higher plant growth was noticed due to N application as N in the initial stages helped to acquire an advantage over control and the poor status of N must also have contributed to the higher response to applied doses of N through fertilizer (Mandal, 2000). Not much difference was noticed due to sources of N it might be due to the fact that the N required in the initial stage was met out by either of the source equally.

S application also had a positive effect on enhancing the plant height. The increment was more for the first dose during all the growth stages because the input followed the law of diminishing returns. The response of the crop to S for plant height was diluted at the later stages probably because plant height is a genetic character and the environmental factors can have a slight impact. Chandel *et al.* (2002) also reported the increase in plant height and explained that it might be due to the positive role of S in plant metabolic activities, which lead to higher photosynthetic activity and thereby increase in plant height.

Application of B at different doses also enhanced the plant height as B checks lignification of vascular tissues and there is a continuous growth of the cell. Another reason could be that B helps in cell formation and is also very active in growing tip cells. These results were confirmed by McIlarth and John (1964) and Yu and Bell (1998).

5.2.1.2 Dry matter accumulation

Dry matter accumulation in different plant parts of sunflower increased progressively from 45 DAS till harvest stage during both the years of the field study. At 25 DAS, maximum dry matter was accumulated in leaves followed by stem and roots. The leaves are the main photosynthetic organ and due to enough space available for more canopy coverage, the dry matter accumulation was the highest in leaves. While at 50 and 75 DAS, more vertical growth was experienced to accommodate maximum leaves for higher solar radiation interception. That could be the reason for

higher stem biomass at 50 and 75 DAS. The dry matter production of leaves at harvest was declined due to degenerating and drying of leaves beyond 75 DAS through the process of senescence. There was an increase in total dry matter accumulation although the partitioning was diverted towards developing capitulum. Rodriguez *et al.* (2002) showed that biomass production in a classical growth kinetics exhibit increase in the stem up to harvest. There were translocation and redistribution of photosynthates from leaves and stem to the head and seed, after the flowering stage.

N helps to impart early growth and quick seedling establishment. Hence its application enhanced the dry matter accumulation of different plant parts at different stages of crop growth. Increasing rate of N enhances the germination and dry matter accumulation, which is also an indicator of crop performance. Steer and Hocking (1984) recorded the positive impact of N supply on stem, leaf and capitulum dry matter accumulation. They also found that adequate amount of N at early crop growth stages allowed maximum development of root mass and floret number. Total dry matter accumulation by sunflower plant is a function of various external and internal factors, nutrient supply being one of the important parameter. Among nutrient management, S is an important element to be taken due care of. It enhanced the dry matter accumulation in both above and below ground at all the crop growth stages. In control plot, the ratio of stem:root was very less and as the S dose increased, the ratio widened. This could be due to the fact that under S limited conditions, root exploration is higher and when S is supplied, quick uptake is seen and a good proliferation of canopy is possible. Sunflower being an oilseed crop, its S requirement is higher and is taken up during the entire life cycle of the plant. Oil being the final produce, more dry matter accumulation in head was recorded than by N application.

A higher amount of dry matter accumulation is observed due to B application since it is an important element for growth and production of crops. It enhances the total dry matter accumulation due to cumulative effect on the individual component. Akcam and Demiray (2004) also found that the B application increased root and shoot length due to increase in indole acetic acid (IAA) content which is a growth promoter hormone. B promotes growth by maintaining cell membrane integrity. Cakmak *et al.* (1995) also proved that growth is reduced due to B deficiency. Single B application @

0.75 kg/ha proved very beneficial. The possible reason could be that in B sufficient leaves, leakage of solutes is very low. Leakage of phenolics, amino acids and sucrose increased due to B deficiency. In physiological respect, B application results in immediate decrease in K^+ efflux. Hence B has role in maintaining the integrity of plasma membrane. It also has a protective influence on membrane constituents by complexing phenolics, so that oxidation of phenolics to increased toxicity quinones and O_2 free radicles is prevented or limited. These toxic compounds are responsible for poor leaf growth and untimely senescence. Once, it is checked, there is continuous leaf proliferation and enhanced dry matter accumulation.

Total dry matter accumulation of the plant increased till harvest stage. The contribution of B to total dry matter accumulation was more significant through head dry matter accumulation as B is important for fertilization and seed filling. It is more required for reproductive growth and diverts maximum synthesized carbohydrates towards the sink. The process of dry matter accumulation in sunflower was continuous due to its genetic ability to absorb inorganic material for synthesizing carbohydrate until it matures. Micronutrient like B significantly affects dry matter accumulation. Higher amount of dry matter accumulation with B might also be due to the favourable effects of B on N assimilation and carbohydrate metabolism.

5.2.1.3 Leaf area index (LAI)

Growth indices like LAI depend upon the leaf area expansion in response to sunlight and applied nutrients. During both the years of the field study, LAI increased up to 75 DAS. LAI usually follows a typical quadratic pattern. It increases with good pace initially, reaches a plateau and declines thereafter. The growth of the crop is linearly dependent on LAI, which in turn is linearly dependent on crop biomass. As a result, crop growth and LAI in the initial phase is exponential. Between 50-75 DAS, there was total coverage of the field. At this crop growth stage, maximum leaf expansion was there as nearly 100% of all incident light was intercepted. Beyond 75 DAS, this phase of vegetative growth ends when the plant gets a certain environmental or internal signal and starts generative growth. At this phase, 100% of all production is directed to the reproductive parts, the leaves are still intact and as a result gross primary production (GPP) stays the same. Beyond this phase, leaves and other

production structures slowly die off. Their carbohydrates and proteins are transported to reproductive parts. As a result, LAI decreased and, hence, the primary production decreased. LAI was less during the second year, might be because of slow initial growth and a low base in terms of leaf area on which the further increment was possibly lower.

N application had a profound effect on LAI. At 25 DAS, comparatively higher significant LAI was recorded when N was applied through urea. The reason for this might be that urea provides N in readily available NO_3^- form which initiate quick growth but at later stages, CAN also became equally competent and the effect of urea was diluted.

S application helped to enhance the LAI more sharply with the application of 25 kg/ha than 50 kg S/ha as it brought an immediate change. Higher LAI due to S application was noticed because the leaves are fully functional and expanded. S application helps in vigorous leaf growth and their foliage. Accordingly, more number of leaves with expanded leaf area produced and resulted in increased LAI. Similar findings are reported by Prasad (1999).

The LAI increased up to 75 DAS of growth due to B application as noted in the period of grain filling and reduced thereafter till maturity. B recorded higher LAI at all growth stages due to marked effect in metabolic roles in N assimilation and carbohydrate metabolism, which modify favourably the vegetative growth in terms of leaf area. Higher LAI is indicative of high mobilizable protein pools available at the beginning of the reproductive phase. More is the LAI at start of reproductive phase, greater is the plant bearing capacity later on. The reduction in LAI towards maturity was due to natural senescence of the lower leaves. Other than increasing the total leaf area, B also maintain the functionality of leaves as it enhances the photosynthetic oxygen evolution by leaves, the apparent quantum yield and quantum efficiency of PS II electron transport. Similar results were drawn by Kastori *et al.* (1995).

5.2.1.4 Crop growth rate (CGR)

Crop growth rate increased till 50-75 DAS and declined there after following an exponential relationship with time. Since, CGR is a function of dry matter

accumulated by the plant, it followed the similar pattern and because rate of dry matter accumulation was lower at the last growth stage, CGR values also dropped sharply.

N application had a positive effect on CGR. Significant improvement in plant height and CGR under application of N resulted due to significant increase in total dry matter production. Rate of photosynthesis increased due to appropriate N application with concomitant increase in PAR, internal CO₂ exchange rate (CER), transpiration and decrease in stomatal resistance. Consequent upon, the higher rate of photosynthesis, dry matter accumulation also increased. The crop receiving N treatment maintained higher light interception ratio, LAI, biomass production and CGR that resulted in greater rate of photosynthesis, harvest index and seed yield. That was the possible reason for lower CGR during 2006. Both urea and CAN were equally effective till 50-75 DAS but since CAN accumulated higher dry matter during both the years of the field study, the cumulative effect was sufficient to make a difference till harvest stage.

S @ 25 kg/ha significantly improved CGR at all the crop growth stages but the increase was higher during 50-75 DAS. The possible reason for this explanation might be that the dry matter accumulation/unit leaf area/unit time was higher during vegetative stage than reproductive stage. Better expansion of leaf is associated with enhanced photosynthesis, which could be the reason for S proved more beneficial. These results were also confirmed by Legha and Giri (1999). Reddy and Khera (1999) also found that addition of S @ 30 kg/ha increased total dry matter accumulation separately in leaf, stem and head, significantly. Further increase in CGR was comparatively lower with S @ 50 kg/ha and it could be due to the soil S status which reached at a sufficient level even by 25 kg S/ha. Further application of S had a positive effect but at diminishing rates.

B also recorded an increase in CGR due to parallel increase in dry matter production due to efficient N assimilation and carbohydrate metabolism. Sunflower fertilized with B increased CGR considerably up to 50-75 DAS during both the years coinciding with the period of increasing LAI. This increase might be because of increased vegetative growth of plants due to enhanced photosynthesis, protein and carbohydrate metabolism by B. CGR was increased with increase in LAI till the stage

when maximum LAI is obtained. The decrease in CGR towards maturity might be due to natural senescence of older leaves. Such reductions in CGR at harvest stage were also reported by Sarkar *et al.* (1998). A quick response was observed at 0.75 kg B/ha which was higher than the rate of increase with B application @ 1.5 kg/ha.

5.2.1.5 Relative growth rate (RGR)

Various management practices affect crop growth and nutrient management have bigger role in growth and development of a plant. Crop growth is the result of modifications in various morphological parameters like plant height, leaf area and dry matter accumulation. Any treatment affecting these parameters will ultimately affect the overall growth of the plant. The results of this study revealed that all growth parameters were increased at a faster rate during 50-75 DAS, which could be said to be the peak growing period of the crop. RGR represents the additional gain of dry matter accumulation on a base value. During both the years of the field study, RGR was maximum during 25-50 DAS, and it might be because the dry matter accumulation at 25 DAS was very low and the relative increase from that base value was higher. It declined thereafter because the relative additions became lower.

Application of N is helpful in gaining the dry matter accumulation but RGR was completely higher for control plots because the base value of dry matter accumulation was very low in control plots. RGR decreased with nutrient application because nitrogen use-efficiency of plants become higher, nitrate is reduced, the amount of organic N increases, ensuring that a higher assimilation rate is maintained until NO_3^- reserves are fully depleted. Thereafter RGR declined as NUE of the plants decrease, due to dilution effect on the organic N concentration and reduction in leaf area expansion rates. The decline of RGR with plant N concentration increased dramatically once its entire nitrate has been assimilated and it has been also proved by Walker *et al.* (2001).

Application of S also improved RGR due to good growth attained by the crop under good supply of nutrients was much helpful in utilization of available water and other nutrients during pre-flowering stage. RGR declined thereafter and did not change under S @ 50 kg/ha. This might be due to reduced uptake of nutrients and water as the

roots start getting suberized after completion of active vegetative growth (Russell, 1952).

The RGR reached its peak during early crop growth of 25-50 DAS and then maintained steadily lower rate till maturity. There was however, no discernible significant effect of B on RGR at any crop growth stage. The RGR values recorded under B was more or less same. No definite trend in the RGR values were recorded because of the reason that there was very low rate of increase in dry matter accumulation beyond a certain limit and base level of dry matter accumulation was highly variable (Singh and Agarwal, 2001).

4.2.1.6 Net assimilation rate (NAR)

In the early and late crop growth stages, growth rates were slower. For the former crop growth stage, this is attributable to the relatively less number of cells undergoing cell division, the insufficient leaf area for light interception and photosynthesis and the high proportions of photoassimilates being translocated to roots. Growth rate at the later stage was reduced due to self shading and ageing (Nkoa *et al.*, 2001).

The values of NAR was the highest at 25-50 DAS due to sharp increase in dry matter accumulation and quick early growth and experienced a steady decline thereafter till harvest stage. Leaves are the net assimilatory parts and they degenerate and die off at the later crop growth stage resulting in the decline in NAR. N is the main element required for vegetative growth of the plant. Increase in NAR due to N application at early stages might be due to increase in CO₂ assimilation. In addition, the mobile nature of N also gives significant boost to dry matter accumulation in stem and leaf. Robinson (1980) also confirmed the same results and found that N concentration also enhanced up to maximum growth period of the crop.

Application of S had enhanced the assimilatory substrate for photosynthesis. S application @ 25 kg/ha increased NAR reasonably and at 50 kg S/ha NAR was statistically at par with NAR at 25 kg S/ha. It could be due to the fact that S applied @ 25 kg/ha was sufficient to made a required enhancement and the higher dose was not able to increase the uptake of S by the plant.

Application of B tended to increase NAR probably on account of higher rate of expansion of leaf surface area as B might have played specific roles in enzyme activities. NAR is basically a reflection of growth rate achieved/unit leaf area and as the leaf area component and growth increased in the B fertilized plants, NAR also increased proportionately. The values of NAR were maximum during initial crop growth stage indicating the necessity of attaining a good leaf growth through proper fertilization practices so as to acquire maximum benefit from the leaves in terms of photosynthesis. The fall in NAR from seed filling stage onwards might be attributed to corresponding decline in LAI and apparently due to increase in rate of respiration/unit of leaf area of the plant. Similar results were quoted by Sarkar and Ghosh (1992).

4.2.1.7 Total chlorophyll content

N is the major component hence its application had a direct effect on total chlorophyll content of the leaves. The values were higher during the first year due to higher plant growth, favourable climate and appropriate time of sowing. Chlorophyll content increased till grand growth phase and declined thereafter due to natural senescence. Application of nutrients specially N had a strong influence on chlorophyll content as Marschner (1997) also reported that N is a major constituent of chlorophyll and its adequate supply through fertilizer encouraged the photosynthesis. N source could not have any significant influence as the N required for chlorophyll synthesis was easily met by any of the applied source.

S application had not significant difference in chlorophyll content during 25 DAS, although at later crop growth stages the difference become significant. S is also important for enhancing the green colour of leaves and in its deficiency, mesophyll cell division reduced leading to smaller leaf size and less chlorophyll content of individual chloroplast. Sexton *et al.* (1997) further reported that chlorophyll content, rubisco activity and CO₂ exchange rate (CER) were also declined.

B is required for higher chlorophyll content even if S is present in adequate amount. B deficiency, at normal S concentration reduced flowering, dry matter accumulation, tissue nutrient concentration, chlorophyll content and hill reaction activity (Khurana and Chatterjee, 2002). In a similar study Plesnicar *et al.* (1997) found the same results. B was beneficial at 0.75 kg/ha and also at 1.5 kg B/ha as B

deficiency reduced the dry matter content, leaf area and leaf chlorophyll content. B deficiency reduced photosynthetic evolution per unit leaf area. The reducing rate of photosynthesis in B deficient sunflower leaves could be correlated with the reduction in chlorophyll content and reduced transport of CO₂ and photophosphorylation. All these activities are related to altered chlorophyll content.

5.2.3 Yield attributes and yield

Influence of various treatments containing N, S and B were found to be significant in enhancing yield attributes and yield of sunflower in both years of the field study (Table 15-16 and Fig. 8).

Various yield attributes were found superior in the first year compared to second year and this could be assigned to better growth and development of plants with higher dry matter accumulation, robust growth and increased photosynthetic activity which resulted in higher accumulation of photosynthates during 2005. The yield of a crop species depends on the source-sink relationship and is the cumulative function of various growth parameters and yield contributing characters.

5.2.2.1 Capitulum diameter

Almost equal capitulum diameter was produced by application of N sources during both the years of the study. Increased growth of the head by N application was attributed to better partitioning of photosynthates from source to sink. When N supply is enough the diversion of nutrients towards roots or below ground parts is checked and more photosynthates are translocated to the head at the commencement of reproductive phase. Since, head development occurs late in the growth stage of sunflower, the difference due to urea or CAN almost diluted and both the sources performed equally good during both the years of the field study. Such results have also been well documented by Sadiq *et al.* (2000).

S application was also very beneficial to enhance the capitulum diameter. Since, it is an element inevitable for oilseeds, its more diversion is required towards the head. It helps in the proper head: leaves dry matter accumulation ratio. During both the years, S application @ 25 kg/ha was more effective to increase capitulum diameter than S applied @ 50 kg/ha.

B has a specific role to follow for oilseeds. B requirement of sunflower during reproductive growth is repeatedly much higher than during vegetative growth. B application increased the vegetative and reproductive dry matter accumulation of plants by more than 3 folds, including that of the capitulum. B influences cell development and elongation of cells through control of polysaccharide formation. It prevents the excessive conversion of sugars into starch. Hence it continued the growth of the head, which resulted in bigger size of capitulum. B regulates photosynthesis and respiration by maintaining carbohydrate and protein metabolism. B enhances the starch synthetase activity, which increases concentration of starch in the leaves; otherwise the accumulation of sugars in the leaves might impede translocation of sugars from leaves and stem to the head. Thus B deficiency leads to callose formation in sieve tubes, which reduce formation of sugar-borate complex ultimately lowering, sink capacity and reduced capitulum diameter (Dugger, 1983).

5.2.2.2 Number of seeds/capitulum

Number of seeds/capitulum is an important yield attributing character, which decide the quantum of yield. Number of seeds/capitulum were more during first year than in the second year of the study and because it was dependent upon adequate storage of plant nutrients in leaves and stem which were higher in 2005. Later, these nutrients were translocated to the head. N plays pivotal role in increasing number of total seeds with successive increase in N levels. Increase in total number of seeds was due to better assimilation of carbohydrates. Numbers of seeds/capitulum were higher with CAN as a source of N in 2005 and it might be due to higher rate of mineralization of CAN under higher temperature. If the per cent total amount of N is seen and how it is distributed among various plant parts, 82% of the total amount of N was accumulated in the head, which indicate the prime importance of N for seed development in head (Oyverman *et al.*, 1995). Hence nutrient application must precede plant uptake pattern because uptake is enhanced at higher ion concentration around the roots.

S application becomes important for sunflower, since it is an oilseed crop. Its timely application increases the plant growth, increases assimilating surface and the higher photosynthate assimilation helped for net export of carbon to sink and thus

increased the number of seeds/capitulum. The slight difference between the response of 2 doses of S during both the years could be due to difference in the N:S ratio. Hocking and Steer (1983) also drew the inference that the deficiency of S was responsible for rapid senescence, reduced dry matter production, reduced leaf area ratio (LAR) and low number of seeds/capitulum.

B is very beneficial to increase number of seeds/capitulum. During both the years, a significant increase in the number of seeds/capitulum was observed. B influences flowering, pollen germination, fertilization, cell division and water relationship. B deficiency results in failure to set flower or cause flower abortion. Number of seeds/capitulum increased with B application as it increases pollen-producing capacity of anthesis and pollen grain viability. B demand for seed production is higher than that needed for vegetative growth alone. Numbers of seeds/capitulum were lower without B because under B limited conditions, accumulation of phenol is in larger quantities in stigma during anthesis resulting in poor pollen germination and poor fertilization. Such reports are also given by Shen *et al.* (1995). Tip growing pollen tubes have high pectin content in their apical cell wall, which is cross-linked with Ca and B. Under B deficiency, tip growing pollen tubes burst at their apices resulting into barren head due to poor pollination, which could be another reason for low seeds/capitulum. The results were also confirmed by findings of Baluska *et al.* (2002).

5.2.2.3 1000-seed weight

A higher test weight was noticed during 2005 than 2006 due to bold seeds obtained/head. Significantly higher test weight was noticed with N due to overall productive growth of the crop. Since, the mineralization of N could not make much difference to the test weight, both urea and CAN were statistically at par with each other. Application of S was beneficial but S applied @ 50 kg/ha could not cause much difference and it might be because of the sufficient initial S status of the soil.

B deficiency is often an unsuspected enemy as it has strong role in seed formation. Even a crop with high vegetative growth and proper flowering can lead to poor seed setting due to B deficiency. The partial or complete failure of fertilization leads to fruit/seed drop, deformed and shrinked seeds and partially filled seeds, which

result in, lower test weight (Shrotriya, 2002). Another reason for lower test weight could be that concentration of sugars reduced in seeds due to improper utilization of sugars in B deficiency. Starch concentration in seeds also reduced due to lower activity of starch synthetase. Similar reasons for poor seed weight were also given by Agarwal *et al.* (1981).

5.2.2.4 Seed yield

The yield of the crop is final product of various yield-attributing characters. The effect of any treatment on yield attribute is directly reflected in the yield. Seed yield was obtained higher in 2005 than 2006 due to favourable weather conditions and optimum growth factors. Temperature fluctuation and rainfall variation caused reduction in yield during 2006.

Even then, the effects of various fertilizer treatments were visible during both the years the fields study. Both the N sources had a positive effect on seed yield increase. The higher availability of nutrients, especially N in the initial stage helped to acquire a definite advantage over control in respect of growth. Better partitioning of photosynthates from source to sink might have led to higher yield attributes, which finally resulted, into higher yield of sunflower.

Application of S was also beneficial for seed yield increment. Between both the doses, S applied @ 25 kg/ha was more responsive than 50 kg S/ha as the magnitude of response depends upon the native S status of the soil. The seed yield is generally found maximum when N:S ratio in plant is about 10:4 (Raju and Sreemannarayana, 1998).

Increase in yield by B is attributed to more favourable translocation of metabolites and carbohydrates to seed through efficient phenological activities in plant as evident from the growth parameters like dry matter accumulation, LAI, CGR etc. Yield enhanced due to B application was probably because of a good balance between photosynthesis and respiration. Since, the final yield depends upon the translocation of photosynthates from the source to sink, B is supposed to play an important role here. B maintains assembly and mechanical properties of cell walls, it maintains structural and functional integrity of cell walls. B removal alters cell wall physics, with a transitory

decrease of elasticity modulus and followed by a secondary hardening and a reduction in incidence plasma-membrane bound reductase activity for better translocation to sink. This reduces the total seed yield as reported by Yu *et al.* (2002).

5.2.2.5 Total biological yield

It is a summation of seed and stover yield. Higher the seed and stover yield, more will be total biological yield. It was higher in 2005 than 2006 due to improved growth conditions with respect to soil and climate. A higher dry matter accumulation in all plant parts was responsible for higher total biological yield. N application imparts quick vegetative growth and higher canopy development, which increased total biological yield. S also plays an important role in vegetative growth and it improves seed yield of sunflower as well, hence a higher biological yield was noticed during both the years, although the response was higher at S applied @ 25 kg/ha. B is important as its deficiency produce flower with damaged pistils. Without B application majority of the pollens are aborted. Lack of B causes typical seed malformation, seed number, seed weight and total biological yield reduced significantly (Lieten, 2004).

5.2.5.6 Harvest index (HI)

HI values were higher for first year i.e. 2005 reflecting the better partitioning of dry matter towards economic produce. Higher harvest index with application of N could be due to increased availability of nutrients, which resulted in higher dry matter accumulation, and better translocation of photosynthates as reflected by improved HI (Tomar *et al.*, 1997). High HI with S application indicated that a higher proportion of total biomass was diverted for seed production.

Application of B resulted in higher HI during both the years of the field study. HI is simply the ratio of economic produce to biological yield. When B application resulted in higher seed yield, automatically the HI will be more. Application of B was also helpful in improving HI by another way. The accumulation of dry matter in different parts of the plant and its partitioning is very effectively governed by B. B causes low partitioning of dry matter to stem and thalamus and more towards seeds, hence it improves HI. Genotypes, which include higher biomass accumulation during post flowering stages of development, also showed higher HI and seed yield.

Remobilization of photosynthates from vegetative plant part to the seed results in higher HI and seed yield. Among sink characteristics number of seeds/head, test weight and seed density (seed weight/seed volume) were also higher due to B application, which also contributed to achieve higher HI values (Reddy *et al.*, 2003).

5.2.3 Quality parameters

Quality of harvested product is rather equally important than the volume of the produce. A healthy crop raised under favourable climatic condition, in general give quality produce and here the role of nutrient management becomes significant.

5.2.3.1 Oil content and oil yield

Oil and protein accumulate during maturity at the expense of carbohydrates, sugars, particularly sucrose and its products are the major processors in the formation of oil and hence are consumed in the biosynthesis of lipids. Diglycerides and amino acids are the metabolic intermediates in the biosynthetic sequence of lipid and protein formation. N application increased oil content due to a positive impact on conversion of sugar to lipids. N fertilization led to an increase in protein content and reduction in sugar content of the leaves at flowering with consequent increase in oil content of seeds during both the years of the study. The oil content was higher in 2005 due to favourable temperature at oil synthesis in the seeds. Similar results were also given by Hussain *et al.* (1998). N source could not make much difference because the quantity of N required for oil synthesis is equally met by both urea and CAN. Oil yield is derived parameter from oil content and seed yield. Where there will be higher oil content, there will be more oil yield as well.

Application of S @ 25 and 50 kg S/ha increased oil content significantly during both the years of the study. The per cent increase in oil content was higher with S applied @ 25 kg/ha. S helps in biosynthesis of oil. Application of S to plants enhanced the formation of acetyl CoA, a precursor compound for the synthesis of long chain fatty acid, resulting in increase in oil content which ultimately led to greater oil yield. There is a strong positive correlation between S and lipid content in the seed. S application increases oil content of seeds due to enhanced RNA content also. The quantity of oil content increased more by S than by N application because S had a

positive direct effect on oil content as well as indirect effect on N use also. The oil content enhanced at higher doses of S, may be because of S additions improved NUE when applied at higher doses. The total dry matter production and oil content were increased when S was applied. N and S nutrition during the growth are tightly linked. Their interaction, as reflected by plant uptake is synergistic when both are at optimum level. Hence, S fertilization is required to improve NUE and thereby maintaining a sufficient oil level and fatty acid quality (Fismes^{et al} 2000).

Application of B enhanced reasonably the oil content during both the years. Crop quality like oil and protein content are more sensitive indicator for low B than vegetative growth. B deficiency not only reduces yield, tissue B content, protein in seed but also reduce oil content due to indirect effect of B on fat synthesis. B improves oil content, as it is necessary for cell wall formation, Ca uptake and aid in the translocation of sugars. B influences the movement of hormones, N metabolism, fat and protein metabolism also. These are the major reasons why oil yield enhanced due to B application. These results are in line with the findings of Mahajan *et al.* (1994).

Oil yield was enhanced along with total S uptake as the application dose of S was increased. The coefficient of determination ($R^2 = 0.75$) indicated a strong positive correlation between S uptake and oil yield because of the role of S in synthesis of oil. The regression equation was in logarithmic form and per unit increase in S uptake increased about 3-4 kg oil yields per hectare.

5.2.3.2 Protein content

Protein content is a function of a N concentration in the seed. N concentration was higher in the seed during 2005 due to mineralization of fertilizers coinciding with the crop demands. Due to favourable growth an optimum translocation of sugars and photosynthates was observed which resulted in higher N concentration in seeds.

Protein content is a qualitative trait and is significantly influenced by N application management. N application results in increased seed protein content, oil and protein yields/ha. Increased N concentration helped in enhancing protein content in seeds and increasing external N concentration during reproductive growth can increase seed protein content. N plays a crucial role in maintaining protein: oil ratio in

seed. N fertilization is advantageous to improve protein content and maintain concentration of essential amino acids as reported by Sawan and Hafez (2001) and Nakasathin *et al.* (2000).

S application enhanced the protein level during both the years and the increase was up to 10% with S applied @ 50 kg/ha. Application of S to plant enhanced the protein content as it resulted in stepped up synthesis of S containing amino acids, which are building blocks of protein. It also resulted in higher oil content because of higher synthesis of protein containing S in oil storage organs of oilseed crops (Panda *et al.*, 2000). Another possible reason for enhanced protein content could be an encouraged activity of nitrate reductase enzyme due to application of S, which alters protein and N metabolism. Not only content, but also the nutritional value of protein could also be enhanced by increasing the amount of S-containing amino acids like methionine, cysteine and cystine. N assimilation and protein synthesis declined due to increase in the amount of free amino acids and nitrate in leaves when S is limited. S deficiency also limit photosynthetic rate by limiting protein synthesis as a result of decline in rubisco activity.

Application of B also had a positive effect on protein content of the crop. During both the years, an increase up to 10.15% has been noticed in protein content due to B application @ 1.5 kg B/ha. The increase could be due to a direct effect of B on N metabolism, for example nitrate reduction, amino acid and protein content. The effect of B on sugar metabolism is also seen due to its effect on intermediates, which influence the partitioning of carbohydrates fluxes between glycolysis and the pentose phosphate cycle. These observations were in line with findings of Marschner (1995). Another reason for low protein content in seeds due to B deficiency could be low RNA synthesis and high RNAase activity. Phenols are accumulated in the seeds due to B deficiency because B is known to play a key role in regulation of pentose phosphate pathway (PPP) *via* the formation of acid-borate complex which indirectly affect the formation and development of seeds as a consequence of which seed quality is deteriorated as also reported by Mahajan *et al.* (1994).

5.2.3.3 Fatty acid composition of sunflower oil

Soluble sugars, total diglycerides and free amino acid reduces while total oil and triglycerides increased with maturity. Oils are made up of fatty acid and glycerols. Fatty acids are of two types depending upon the chemical structure, i.e. saturated fatty acids (SFA) and unsaturated fatty acids (UFA). Cultivated sunflower seed oil contains approximately 10% SFA mostly palmitic and stearic and 90% UFA, mostly oleic and linoleic. The content of linoleic and oleic were higher during the first year due to higher temperature noticed near maturity. These results were confirmed by Giriraj and Nagraj (2003). It is desirable to have high oleic acid as it improves shelf life and oxidative stability. Although it is monounsaturated fatty acid, it is equally effective like polyunsaturated fatty acid (PUFA) in reducing serum total and low-density liquid (LDL) cholesterol. Interestingly during both the years, a similar trend was seen that when linoleic acid increased, oleic acid reduced and *vice-versa* as Rani *et al.* (2006) also showed negative correlation of oleic acid with linoleic acid. In body PUFA are important for maintaining the membrane of all cells, for making prostaglandins, which regulate many body processes, which include inflammation and blood clotting.

N application increased the desirable linoleic acid content and it might be due to N application, there was increase in dry matter accumulation and oil accumulation phases, with all the enzymatic activities involved, including 12-desaturase which is responsible for the desaturation from oleic to linoleic. Therefore an increase in linoleic acid was recorded. Baldini *et al.* (2004) also confirmed these results. The oleic acid content is also higher due to N application as N application changed seed oil constituent altering the oleic and linoleic acid ratios. Ninyi and Gandhi (1994) also concluded that oleic acid content was increased from 24.5% to 28.5% with N application @ 80 kg N/ha. Similar reports of increase in UFA and a decrease in SFA have also been reported by Ashraf *et al.* (2003). N sources could not bring any change to the fatty acid composition because N application through any source before floret initiation may influence leaf mass etc. but these characters have no effect on oil quality (Steer and Seiler, 1989). The fatty acid composition of sunflower oil was changed by B application, of course, a higher amount of UFA and a lower SFA was due to the fact that B inhibit acetate incorporation into lipids which enhances the UFA:SFA ratio, as also mentioned by Belver and Juan (1987).

Other quality parameters like saponification value, iodine value and acid value were also influenced significantly due to application of various fertilizer treatments. N application decreased the saponification value. The higher N application resulted in an increase in seed oil refractive index, unsaponifiable matter and total UFA. The SFA of the oil also decreased. The increase in unsaponifiable matter is beneficial as it increases the oil stability. N application could bring better impact on yield, seed protein content, oil refractive index, unsaponifiable matter while it reduces acid value which is measure of the content of free fatty acids in fats and oils. They reduce the oil stability and deteriorate its quality. These results were confirmed by Zakaria *et al.* (2006). The reduction in oil acid value occurred with the fact that tocopherol content increased with increase in N application (Holmes and Benett, 1997).

Iodine value is the direct measure of unsaturation of fatty acid. Higher the iodine values, higher is the unsaturation with increasing N levels, the iodine value increased as also seen in the experiment during both the years due to inhibition of desaturase enzyme (Ninyi and Gandhi, 1994). But the N sources were more or less the same to cause any significant difference, as also reported by Singh *et al.* (1987).

S application increased iodine value but reduced saponification value and acid value by enhancing the oil quality. S dressing to sunflower provide sufficient period for polyunsaturating system, which reflected in higher iodine value and less synthesis of free acid (Arora *et al.*, 1994). Likewise B increased iodine value and reduced saponification value and acid value of the oil indicating formation of high molecular fatty acid with less saturated FA to improve quality of the oil.

5.2.4 Nutrient concentration and uptake of nutrients by sunflower

The concentration of both macro and microelements were influenced by direct fertilization of the sunflower plants (Table 20-41 and Fig. 10-21). The content of all nutrients in plant was found to decrease except B as the plant advanced from 25 DAS to harvest. It might be due to the dilution of nutrient concentration and the addition of more dry matter accumulation.

5.2.4.1 Nitrogen

N application significantly influenced the concentration of N in different parts of sunflower plant. This was because of the poor N status of soil and immediate availability of soluble N to plants. The concentration of N is dependent on the dry matter accumulation and therefore, as and when dry matter accumulation was beyond a certain limit, there was reduction in the content. That could be the reason why the N concentration was higher in 2006 at some cases even when the same nutrient amount was applied. Sunflower accumulated N mostly in leaf petioles during the initial 3 stages of its development i.e. up to 75 DAS. The maximum concentration of N during maturity was in seeds due to root nutrition during seed filling and its reutilization from the vegetative organs and the inflorescence. At flowering, the stem had most of the plant's dry matter and the leaves most of its N. The stem was most important for storage of carbohydrates, leaves the most important for N. Similar results were obtained by Hocking and Steer (1983). They also concluded that mature seeds had 38% of the total plant dry weight and 68% of the total N and interestingly seeds acquire 33% of their dry matter and N from redistribution from above-ground plant parts.

N concentration of roots at harvest stage was very low because most of the N was translocated to the above ground parts due to highly mobile nature of N in plants. Specific soluble protein and amino acid appear to be the major N pools mobilized from roots to shoots. It can be proved as if shoot is removed, it reduced root N uptake and nitrogenase activity leaving roots as the primary source of N. Carbohydrate and protein in roots provide C and N for shoot growth. During the vegetative stage, the leaves are the highest nutrient-demanding organs because of their high metabolism activity. This cause of lower quantity of N concentration in roots was also given by Volenic *et al.* (1997).

N concentration was higher in the seed for protein and oil synthesis. The N requirement for protein synthesis in the developing seed was met by the remobilization of previously assimilated N present in the vegetative tissues (pre-anthesis source), due to which the N concentration in stem and leaves declined near harvest stage during both the years of the study. Some of the N requirement can also be met out by direct uptake and assimilation of N during grain filling (post anthesis source).

Retranslocation of previously assimilated N seems to be the predominant source of N for the seed. These findings were in line with the conclusion of Bulman and Smith (1994). Partitioning efficiency of plant dry matter (HI) and nitrogen harvest index, NHI (Seed N/Total above ground plant N) are determinants of economic yield and protein content in seeds. Seed N concentration is determined by total plant dry matter and N accumulation, also upon partitioning of dry matter accumulation and N between seed and vegetative organs. Because the seed N concentration of sunflower is higher than the N concentration of vegetative organs at maturity, there is often a positive correlation between HI and NHI. Greater N inputs applied at flowering can result in increased HI accompanied by a low NHI. The role of N partitioning in different N concentrations of grain was also confirmed by Cassman *et al.* (1992).

Application of S also had a positive correlation with N concentration in plant parts due to synergistic relationship between them. The N:S ratio of crop widened with the age of the crop particularly at 25 kg S/ha indicating high utilization of N, besides higher uptake of N also. The synergistic effect of N and S was also reported by Rattan *et al.* (1995). Also the application of B enhanced the N concentration of different plant parts at various crop growth stages due to its role in N metabolism. A deficient level of B decreased the total N content and it could be due to reduced activity of nitrate reductase and increased content of NO_3^- in roots and shoot of the plant. The study by Kastori and Petrovic (1989) concluded that one of the factor influencing the primary assimilation of N is B supply to plants. The possible effect of B on nitrate reductase activity is via the metabolism of nucleic acids and proteins with energy turnover.

Uptake of N followed the pattern of dry matter accumulation in different parts of sunflower plant (Table 22-23 and Fig. 10-12). Early availability of N coupled with higher accumulation of dry matter resulted in higher total uptake of N at all the crop growth stages. The effect was less apparent in initial stages and became more prominent as advancement in crop growth. The uptake was lower in the early growth stage and increased thereafter till maturity. The uptake of N was more by leaves than stem. At harvest stage, maximum uptake was experienced by seed. In the second year, the data for N uptake was comparatively lesser due to lower dry matter accumulation and low temperature which was responsible for lower mineralization of the fertilizers

N. N has the highest values of uptake followed by K and P throughout the plant ontogenesis. N provided to the developing seed comes from continued N uptake and assimilation after anthesis and from the translocation of previously accumulated vegetative N. N uptake is highly correlated with total dry matter accumulation after anthesis, total plant and seed N per plant. Although N uptake often declines after anthesis, but plant still retains the ability to absorb N and appreciable quantities of N can be assimilated during grain filling.

Higher uptake of N due to S can be justified because of the synergistic interaction between N and S in sunflower, as also reported by Harkal (1996). Application of 80 kg N/ha increased the S content in seed and stalk of sunflower and also S and N uptake by sunflower. Increase in root hydraulics might have encouraged the sunflower plant to absorb higher S. Hence S and N had a positive effect on each other's uptake.

B also had a significant influence on N uptake. B applied @ 0.75 kg/ha responded more effectively than @ 1.5 kg/ha. B markedly affects N uptake and the metabolism of N compound and that the protein contents of young leaves decreased and soluble N compound particularly NO_3^- accumulate under the condition of severe B deficiency. The increased NO_3^- content might be the result of intensified NO_3^- uptake and/or decreased nitrate reductase activity. Such results were also confirmed by Shen *et al.* (1993).

Total N uptake by sunflower also followed the pattern of N concentration in individual plant parts. At harvest, since the N concentration was quite higher in seeds of sunflower than the stover. Therefore, the uptake was also higher in seeds during both the years of the study. N had a significant influence but both the sources were at par with each other. S and B doses were important to improve the total uptake of N, however, lower doses of these two elements were found to be more effective following the quadratic response.

N uptake is enhanced by application of different nutrients as it has a synergistic effect with both S and B. Per unit kg application of S enhanced the uptake of N to 0.20 kg while per unit kg of B enhanced the N uptake by 6.94 kg/ha but the coefficient of determination were almost same for both S and B. The slope was higher

with B due to its low dose of application. Only 2 doses i.e. 0.75 and 1.5 kg B/ha were correlated and beyond that limit the slope may decline.

5.2.4.2 P concentration and uptake

P concentration in different parts of sunflower plant at different crop growth stages were more or less similar during both the years of the study (Table 24-25 and Fig. 13) since no P from outside had been supplied. If any difference was there it was because of the difference in the initial soil status or the amount of dry matter accumulated and its P concentration. Stem recorded higher P concentration than leaves throughout the growth stages of the crop. At harvest stage, maximum P concentration was observed in the seeds followed by stem, leaves and minimum in roots. The reason for this might be that the leaves and stem would compete for P in a similar way. Roots appeared least demanding organ as P has to be sent to the reproductive parts due to remobilization from vegetative parts. Initiation of accelerated growth of reproductive parts, especially seed filling and development seeds become most P consuming organ. Such reasons are also given by Snapp and Lynch (1996) and Volenic *et al.* (1997). P remobilization from leaves and stem is experienced during the later crop growth stages that could be the possible reason for a steady decline in P concentration in the vegetative parts. P remobilization from mature and senescent tissue to actively growing sinks are important determinants of crop performance. It occurs late in the ontogeny since plant nutrients are transferred from aged roots also to actively growing reproductive tissue in a fashion analogous to remobilization from leaves. The S:P ratio showed increasing trend with advancement in age of the crop and with increasing levels of S application. Differences in P concentration due to different N sources was also non-significant at almost all the stages in different plants parts except for leaves at harvest and in seeds. It could be due to an effect on the dry matter accumulated at this stage.

Both positive and negative interactions have been reported between S and P but actually the nature of S-P interaction depends on their rate of application and native status of soil. S and P interaction is synergistic at low to medium levels of P and become antagonistic only at higher rate where very high doses of either S or P are applied (Ali, 1991). The synergistic effect of S and P is also reported by Rattan *et al.*

(1995). Tandon (1986) reported the antagonistic relationship of S with P only at very high level when at least one of the elements is in toxic level in the soil. Since our soil of experimental area was low in N and medium in P therefore, the interaction was found to be synergistic.

Application of B was also beneficial for enhancing P concentration in all the plant parts. The possible reason could be that B maintains a good cell membrane integrity. Due to B, there is an alteration in cell wall physics, with a transitory reduction in the elasticity modulus and followed by secondary rehardening and a reduction of inducible plasma-membrane bound reductase activity. This structural alteration of the pectic-matrix due to B maintains cell wall-plasma membrane-cytoskeleton continuum and allow more P concentration to accumulate in the cell and further transport it to growing parts. Baluska^{et al}(2002) also gave this reason for high N concentration due to B supply.

P uptake by sunflower was very high due to application of different fertilizer treatments. The uptake was higher by leaves in both 2005 and 2006 at 25 DAS. After that, stem became the major P uptake accumulation part. At harvest, maximum uptake was in seeds because other vegetative parts die off and maximum remobilization towards seed took place. In 2006 also, P uptake followed similar transformation, its highest uptake was registered in the seeds at maturation stage, and this higher uptake was due to P reutilization from the vegetative to the generative organs, besides root nutrition during seed filling. P uptake rate with stem and leaf depended more on the P concentration in the respective organ than on the value of biological yield, the case was opposite with P uptake in seeds. The uptake was significantly influenced by N, S and B treatments due to their effect on the concentration of P in plants affected by the type of interaction involved.

In the present study, the uptake of P was also enhanced with S and B doses. The typical S and P antagonistic is visible only when either of the element is present in excess quantity. Since no P was applied from outside, hence a synergistic effect in P uptake due to S application was seen. Coefficients of determination (R^2) were more than 0.50 for both S and B.

5.2.4.3 K concentration and uptake

Although there was no direct K application in the experiment but due to application of other nutrients, its concentration was changed as the uptake of all nutrients are related to each other. The concentration of K enhanced with time as K is subjected to luxury consumption that is plant will take up much more than is needed. Indeed plants will take up all the available K as rapidly as possible and store it for potential use. Initially, the ratio of K concentration in leaf and stem was not much higher but at mass flowering significant increase in K occurred in leaves and to a lower extent in stems. At maturity, a high concentration of K was in seed but less than the vegetative parts, especially leaf and stem. At maturity retranslocation occurs and interestingly for K, at seed maturity, translocation was lower towards seeds which reached to about 30% of that of translocation to leaves and stem. K showed the lowest level of remobilization to the seed, with maximum accumulation at the beginning of the seed formation, this K concentration pattern has been established earlier also by Zerche and Ewald (2005).

A progressive increase was noticed in K concentration due to S application in all vegetative plant parts. S induced high tissue K concentration. Such a situation could occur due to increased metabolic activity involving K related enzymes. The enhancement could also be due to synergistic effect of S with K that is why S enhanced higher concentration, uptake and recovery of K (Islam *et al.*, 1992, Pasricha and Aulakh, 1991).

Effect of B on K concentration could be attributed to its role in membrane integrity and conductance. B has considerable effect on H^+ pumping and passive H^+ conductance. Due to B application membrane fluidity is increased, protein leakage was reduced in microsomal vesicles and enhanced H^+ gradient formation in microsomes of sunflower cells takes place due to enhanced H^+ -ATPase activity and increased passive conductance across the membrane. K^+ is a monovalent cation hence its uptake is easier than divalent cations. The results were confirmed by Ferrol *et al.* (1993).

Large amount of biomass is locked up in the vegetative plant parts, any practice to manipulate the mobilization of photosynthates from vegetative part to head, improve HI and thus seed yield. N enhanced the K uptake indirectly by producing large canopies and higher vegetative growth when there is more growth of roots and shoot the uptake of other nutrients will be automatically higher. More rhizosphere exploration and K extraction is must for maintaining the higher canopies. Uptake of K is also increased due to higher levels of S by various plant parts, leading to increased total K uptake. So was the case with B also. If any plant nutrient is involved in enhancing the vegetative growth will certainly enhance the uptake of all nutrients which are required to maintain the growth. The total uptake of K was higher in stover than in seed due to both the facts, one being higher K concentration in stover and another is due to higher biomass of the stover. During both the years, crop followed the similar trend due to almost equal situation with respect to K availability. These conclusions were also made earlier by Tripathi and Sharma (1994).

Total K uptake by sunflower was more positively correlated to doses of S and B than total P uptake. The coefficients of determination were very high for S doses and K uptake. Due to higher root proliferations with nutrient application, the K uptake increased but it is very less translocated to the final seeds and most of the part is retained in the stover.

5.2.4.4 S concentration and uptake

S concentration and uptake by sunflower crop mentioned in Table 32-33 and Fig. 15-16 showed that the concentration of S is higher in early stage and declined thereafter due to dilution effect where the S has to be redistributed in the entire crop canopy. S concentration was observed slightly higher in stem than leaves. S resembles to N in its role and function and in plant production. However, in terms of overall crop requirement it is very similar to P and could be equated with K in terms of per unit cost. The increased uptake of S with increasing S level can be ascribed to the increased concentration of available S in the soil. S concentration and uptake both increased significantly with increasing rate of its application. Leaf S concentration decreased over time especially at the terminal stage of the experiment at which time leaf N content also decreased (Paparouzzi *et al.*, 1994). The S concentration of stem was

higher initially because the root and stem are the most important sinks for S from the cotyledons but as growth proceeds the stem became the dominant sink for remobilized S. These results were established by Sunarpi and Anderson (1995) also. The concentration of S in different parts of sunflower at different crop growth stages differed significantly indicating their differential S requirement. An increase in S level increased its concentration in all the plant parts due to higher availability of applied S and its rapid absorption and translocation to other parts. A gradual decline in S concentration of sunflower with the advancement in age of the crop is due to greater leaf:stem ratio than at earlier stages. The response of greater amount of S at bud and flowering stages confirms that sunflower plant requires more S supply at these stages to effectively carry out photosynthetic activity due to involvement in synthesis of chlorophyll and at later stages for oil synthesis.

Application of N and S are interconnected in plants. By considering the role of N and S in plant metabolism and protein synthesis including more efficient use of N, conjunction of N with S is important. The proportion and concentration of S were significantly lower in low N seedlings than in high N seedlings because of lower net uptake of S. Application of 80 kg N/ha increased the S concentration in seed and stalk of sunflower and also N and S uptake by sunflower. Increase in root hydraulics conductivity might have encouraged to absorb high S. Hence, S concentration in seed and stalk was increased due to N application. Increase in N and S uptake due to N application could be due to combined effect of increased N and S concentration in sunflower and higher biomass production (Legha and Giri, 1999).

Increase in S concentration because of B application could be due to the synergistic effect of S and B in plants. High B also enhanced higher S concentration (Dangarwala *et al.*, 1994). Uptake of S was more in seed than stover due to higher S concentration in seed. Even the stover yield was higher but the concentration was very low to make any significant difference during both the years.

5.2.4.5 B concentration and uptake

B concentration was higher in leaf than stem at all the crop growth stages till harvest (Table 36-37 and Fig. 17-18). There is an increase in B concentration of leaves and stem till 75 DAS and declined thereafter. At harvest stage maximum B

concentration was in seeds followed by leaf and stem with minimum in roots. Toru and Kumiko (2005) also reported the same results that 80% of the newly taken up B is preferentially transported to the shoots. The total B content of plant sample is higher before fruit set and it declined after fruit set, possibly because of movement of B complexes to the seed. Due to B application cell membrane exhibit significantly higher depolarization with 10 folds increase in nutrient flux than without B. B induced higher nutrient uptake due to stimulation of H^+ -ATPase (proton pump) with the subsequent hyperpolarization resulting in an increased driving force for nutrient influx (Schon *et al.*, 1990; Polat and Bayrakli, 2003).

When plants are supplied with N, the demand for B increases that could be possible reason for high B concentration due to N application because B is required for proper utilization of N in the plant system. Such reports were also given by Teasdale and Richards (1990). A synergism between B and S was reflected when B deficiency effects were accentuated further by combined deficiency of both nutrients. No seeds were formed in B deficiency regardless of S levels. Such conclusions can be drawn on the basis of the studies of Karle *et al.* (1995) and Khurana and Chatterjee (2002). The total uptake was higher in seed due to considerable higher concentration of B in the seed of sunflower, which was significantly affected due to various treatments of N, S and B itself during both the years of the experimentation.

S and B uptake in seeds was positively correlated to the doses of both S and B, which enhanced the uptake in the plant. At the time of translocation of photosynthates into sink during maturity, the higher remobilization of S occurs than B as B is bound tightly in the cells and is considered as highly immobile in plants. Whereas, most of the S is directed towards developing seeds from the stover and hence the coefficient of determination was higher between S uptake in seeds and S uptake in stover than between B uptake by seed and B uptake by stover.

Nutrient use efficiencies, specially in terms of physiological aspects for retranslocation and remobilization in seeds once taken up by the plant when studied, it was found that among N, P, K, S and B, physiological efficiencies of N and K were lower i.e. 16.92% and 18.85% respectively than P, S and B, where the efficiencies were 48.42%, 75.77% and 27.32% respectively. For N, the efficiency could be lower

because sunflower being an oilseed crop there is more use of S and B for biosynthesis of oil. K is highly subjected to luxury consumption, specially when the soils are not deficient in available K. Therefore, more is available K, more will be the uptake, even though the proportionate amount is not translocated to the developing seeds.

5.4.5 Available nutrient status of soil

Results in Table 42-43 indicated higher availability of all the nutrients (N, P, K, S, B) in soil after the harvest of sunflower. This is obvious because sunflower crop might have not fully utilized these nutrients because of slow rate of mineralization and short crop duration. This was also reflected on the higher yield of succeeding mungbean crop from these treatments. The initial status of soil was different in both the years at all the 3 depths 0-20, 20-40 and 40-60 cm. Even with different status of soil, the residual nutrients were higher in the second year because of the lower temperature in the initial stage of second year due to which mineralization and solubilization of applied nutrients might have fallen.

5.4.5.1 N

The highest available N was observed at the upper layer of 0-20 cm soil. Then a decline was observed till 40-60 cm soil depth. No change was observed during any of the year due to change in N source. The available N was higher at the upper layer because of the fact that the fertilizers were applied in the top layers. Sunflower is a heavy feeder of nutrients specially N. N is required throughout the life cycle of the crop and since it was applied in 2 splits, the possibility of N losses was also less. There was a slight increase in the available N at lower layers due to leaching of NO_3^- along with rainwater and irrigation water. During 2006, a slight significant increase was observed due to CAN as a N source because of low temperature in the initial growth phase, where losses due to volatilization were checked. Also CAN is less subjected to ammonia loss than urea because it forms soluble Ca reaction products. In CAN, about 10% Ca is available, it forms CaCO_3 which reacts with ammonium form and a precipitate is formed which is less soluble and hence retain more available form of N in soil.

S application enhances the available N status of soil as it alters soil biochemical properties such as enzyme activities, which are influenced by management practices. Addition of S enhance acid phosphatase, aryl surfatase and urease activities. These enzymes mediate transformation of organically bound nutrients into plant available inorganic forms. Enzymes also influence the nutrient supply in soil. Hence application of S changes the soil atmosphere. It was more beneficial at 25 kg S/ha than 50 kg S/ha. Similar results were also seen by Baligar *et al.* (2005). B application @ 0.75 and 1.5 kg/ha enhanced available N due to an indirect effect. Any NO_3^- fertilizer applied in the soil is reduced to nitrate and ultimately ammonical form. The key step in reduction of NO_3^- into ammonical form is catalyzed by nitrate reductase enzyme. B enhances NO_3^- reductase activity and hence increases the amount of available N in the soil (Marschner, 1986).

5.2.4.2 P

P availability in the soil reduced from the initial status due to the reason that no P was added from outside. There was a reasonably good amount of P uptake by sunflower crop, which was supplied by the previous soil status. P is generally not lost by leaching but surface loss is a great menace. That is the reason why P content was higher in the lower layers. P is generally washed away with irrigation water, particularly from the topsoil. The another problem with P is that it is locked up immediately when the pH is not near neutrality. Application of N, S and B enhanced the P status very slightly than absolute control as fertilizer application increased the less accessible nutrient pools along with the plant available pools. Due to fertilization a higher root exploration and exudates mineralize the insoluble P contents by enhancing the number of microbes and bringing soil condition under favourable situation for nutrient mineralization. These findings were in line with the results of Lehmann *et al.* (2001).

5.2.4.3 K

The amount of available K became higher with increase in soil depth during both the years. Since no K was applied, the content declined from the initial status also. N, S and B failed to cause any significant effect on K availability. K is subjected to luxury consumption i.e. plant will take up much more than is needed and draw

heavily from the soil. Also K is subjected to leaching losses. For these two reasons, K was higher in sub soil layer. Because of luxury consumption, considerable K is removed when the entire plant is harvested. The amount of root biomass removed from the soil reflects that the highest root densities were found in the top (0-10 cm) soil followed by the middle soil layers. Root densities significantly decreased below 40 cm depth by permitting greater access to reserves by nutrients in the upper layer, hence more decline occurs in the top soil (Nuttall and Armstrong, 2003).

5.2.4.3 S

Available S was higher in the upper layer soil, and reduced at the lower depths. The size of S pools during both the years' shows that the available pool is too small to satisfy the crop needs without replenishment. Since there is not a sufficient level i, S input to the available pool was necessary and hence a good response of N, S and B was seen. Input of readily available soluble S fertilizer significantly boosts the size of the available pool and hence the S status of upper soil, but it declined in the end due to more uptakes. Plant available S includes the soluble inorganic sulphate in the soil solution, the surface adsorbed to clay and that portion of the organic S that is mineralized and oxidized to the sulphate form. With increment in depth, the total available S was dominated by adsorbed and non-adsorbed sulphate than a contribution from organic S mineralization, which indicated leaching from the current season S fertilization. This partitioning of S by soil suggests the importance of S fertilization, which must be available during early crop growth to avoid yield damage during early reproductive stage (Baird, 1997). Higher available S in the surface layer might have maintained equilibrium with water-soluble S pool through current application and mineralization of organic S due to dominant microbial activity in the active rhizosphere. Downward movement of sulphate through percolating rain and irrigation water might be the cause of increase in the available soil status in the lower profile. The conclusion was similar to that made by Saha (2003). The another possible reason for higher available S in lower layer could be that sulphate is adsorbed on to soil material (kaolinites and Fe and Al oxides) which are dominant in below soil horizon as also mentioned by Jackson (2005). The increase was made higher with 25 kg S/ha since the higher level of extractable S in the sub surface layer provide an explanation

that S concentration are adequate without S fertilization and hence poor increment was found with high dose of 50 kg S/ha. Most of the S in surface soil is associated with organic matter. Since S and B increases the total microbial population and soil biomass, they also increase the available S level in the soil.

5.2.4.4 B

The available B content increased with increase in depth. The available B level was low in the second year due to the reason that initial level was also low. It significantly increased with N application and increasing doses of S and B. The increase was more during the first year due to altered soil atmosphere because of profused vegetative growth. The level of B was quite adequate in soils of the experimental area. The high B status of the soil of Delhi may be attributed to 2 important factors. The first is the nature of the parent material of the soil. The second reason for relatively higher content of B in soils of Delhi is the quality of irrigation water. In general, accumulation of B in soil increases with the concentration of B in irrigated water. A positive correlation has been observed between water-soluble B and the B in irrigated water. Similar conclusions were also drawn by Kanwar and Mehta (1970) and Sharma and Katyal (2006).

Available B levels of the soils did not differ much along the soil depth. The available B level was slightly higher at higher depths i.e. 40-60 cm. It was related to the soil type and root B concentration. Highest root densities are found in the top soil which permit greater access to the B reserves in the soil. The decline in residual levels of B from single fertilization is related to soil type and leaf B concentration due to leaching of B in lower layers and single B uptake, the soil available B decreased dramatically with a larger decrease found at a depth of 20-40 cm. Such findings were also established earlier by Yang *et al.* (2002).

5.2.5 Monetary returns from sunflower

Net returns, gross returns and B:C ratio of sunflower crop has been estimated during both the years of the study. The returns were higher during the first year due to higher seed and stover yields obtained during 2005. The gross returns were almost same with both the sources of N, but the net returns were higher with urea and

surprisingly the B:C ratio reduced considerably because of the higher cost of purchasing CAN. Although CAN produced higher net returns, urea is an economical source of N as also justified by Freser (2005) and Hollis (2005). Urea is a good source of N to use and the reason for this is comparatively cheaper source than CAN manufacture because of the process used in making it. The process is relatively inexpensive compared to that used to make CAN. Hence it can be concluded that with not much difference in performance between N sources occurred, but the price per unit N matters more. CAN requires almost double the amount of fertilizer per unit of N applied to break even point. Application of S also proved to be economically beneficial but the source selected that is cosavet was very costly and reduced B:C ratio. It would have been more beneficial if the same doses of S were supplied with an alternate source of S like gypsum. Although Krishnamurthy and Mathan (1996) also found higher B:C ratio with S application in sunflower. Comparatively, B was found to be more sound in terms of economics as the source selected was quite cheap and the response obtained was very high specially at the first dose.

Net returns and B:C ratio gives a general and broad idea about the profitability of a particular input but if more precisely one has to know the point up to which input application is beneficial, economic optimum dose has to be worked out.

5.2.6 Production functions and model validation

The production functions developed for N, P, K uptake in growth and yield response of crops under variable B & S indicate the significance of these nutrients which have become limiting in recent times. The results clearly indicated the interaction of these nutrients for uptake of major nutrients, thus contributing to deficiencies in growth and yield of these crops. The present study generates the quantitative approach for evaluating the contribution of application of these nutrients.

These results can be linked with the crop simulation model, such as Infocrop at the terminal stage to alter the growth and yield components of the test crops, which becomes an empirical approach dealing through the technical coefficients generated. Since the present study did not vary much for applications in terms of N, P and K, so the only alternative was dealing with these nutrients at the terminal stage.

Optimizing Fertilizer Use

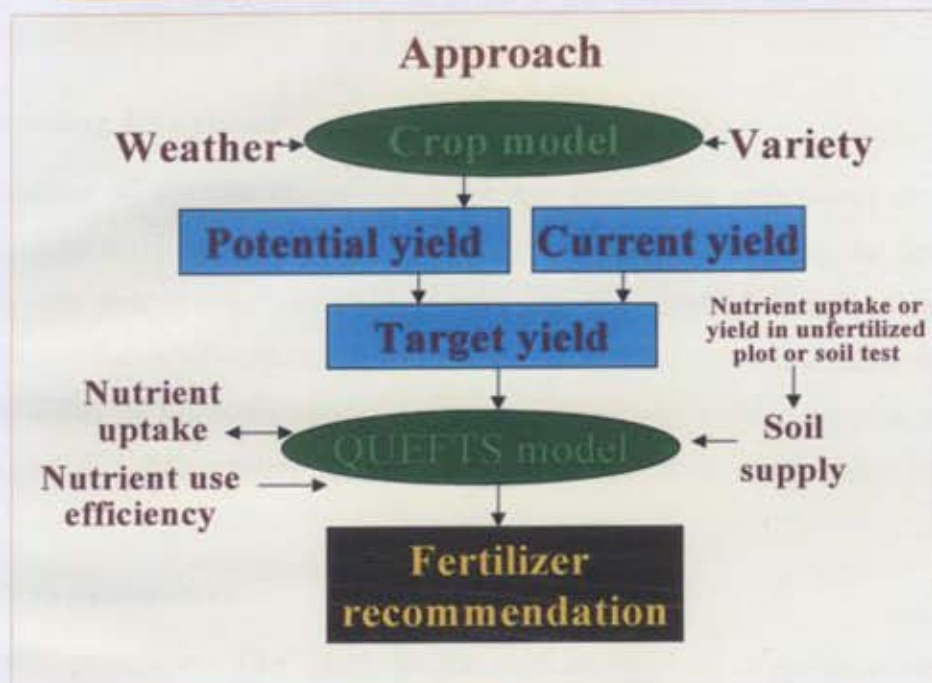


Fig. 24. Nutrient Model for optimum use of fertilizers in crop management

It can be concluded from the study that under varying combinations of these treatments, the fertility/nutrient use efficiencies of individual components as well as their interaction can be evaluated and the existing models such as QUEFTS can be modified for inclusion of micronutrients like B and interaction effects as important component of the study (Jenssen et al., 1990)

The possibility or justification of modifying dynamic model like Infocrop will be very complex and subsequently have limitation of location/time specifically QUEFTS validation can be done on regional basis for guiding customized fertilizer application.

5.3 Succeeding Mungbean

The effect of nutrient management on the succeeding mungbean crop was studied. Mungbean produced higher growth parameters and yield during the first year due to favourable temperature and rainfall and also the residual fertility level was higher. Nutrients when applied through fertilizers require time for mineralization when it is locked up either by microbes or soil complexes. Therefore, a short duration crop of sunflower could not fully utilize the nutrients released; hence a positive residual impact was seen.

5.3.1 Growth parameters

Growth parameters like plant height and number of branches/plant were significantly influenced by the preceding nutrient supply. N nutrition influences the content of photosynthetic pigments, the synthesis of the enzymes taking part in the C reduction, the formation of the membrane system of chloroplast etc. N is important constituent of nucleotide, protein, chlorophyll and enzyme, involve in various metabolic processes which have direct impact on vegetative and reproductive phases of mungbean. Increase in N supply also enhances the number of branches due to higher photosynthates accumulated. Such results were also given by Chaturvedi (2005) and Stephen (2000). N was beneficial to increase the growth of new tissues resulting in increased source strength. S application also increased the biometric observations. In S supplied plants, the leaf area was higher than that in sulphur-deficient plant. The increased leaf area may fix more CO₂ which influence rate of photosynthesis.

Root:shoot ratio also become higher. When S is readily available, the growth of root and the shoot may be enhanced, leading to higher dry matter accumulation and also better partitioning of dry matter. The significance of S was also reported by Badrudin and Shafiquallah (1998). Likewise application of B also enhanced growth by enhancing root and shoot dry matter and root:shoot ratio also. B also enhance mycorrhizal activity and number of nodules. Nabi *et al.* (2006), also reported maximum crop biomass produced with B application. Since RGR is positively correlated with dry matter yield, it produces higher plant with higher number of branches/plant. Plant height showed the highest degree of increment with B and it activated leaf chlorophyll content, rate of photosynthesis and also increased number of nodules (Bhattacharya, 2004).

5.3.2 Yield attributes and yield

Mungbean produced higher yield attributes in the first year due to appropriate nutrient balance and timely sowing. Rain showers were also noticed as and when crop required. All the nutrients had a positive effect on yield and yield attributes. Mungbean produced significantly more vegetative growth and yield components with good amount of N left after sunflower harvest. The production of seeds and haulms increased significantly with preceding N supply as compared to absolute control. Number of pods/plant, number of seeds/pod, 1000-grain weight and grain yield was noticed higher with good N supply. The level of N, even without *Rhizobium* inoculation had marked influence on grain yield. Due to N application, the higher yield attributes were produced, which indicate meristemic activity of plant in poor soil. More findings are in line with work of Singh *et al.* (1999), Srinivas and Mohammad (2002).

S requirement of pulses is much higher than cereals, as it is a constituent of S containing amino acid besides being involved in several metabolic processes. S application exhibit positive correlation with plant height, number of branches, number of clusters, pods/cluster, number of pods and seed yield. These components helped in seed yield improvement. Significant responses of added S to the crop in sunflower-mungbean cropping system were visualized up to 160 kg/ha in terms of grain yield. The higher magnitude of responses were obtained at lower doses of S as direct effect

but residual S effect was higher at higher doses of S as also reported by Malewar *et al.* (1999). Application of primary nutrient elements along with required micronutrient in a balanced manner is an effective proposition for getting higher grain yield of mungbean. That is why B is important and it increased the grain yield during both the years. B recorded higher values for pod weight, grain weight, haulm weight/plant and 1000-seed weight due to B's favourable effect on plant metabolism and N fixation. It favoured better root growth and N assimilation with higher nodulation which in consequence resulted into better growth and development of sink size and ultimately higher yield. Similar results were concluded by Ali and Mishra (2001) and also by Verma and Mishra (1999). The response was higher during the first year because the nature of response of crop to B depends upon seasonal temperature. Maximum response is between 25-33°C which was noticed during 2005. The favourable temperature had a favourable effect in activation of naturally occurring VAM. The yield increment in mungbean due to higher residual B is also because B is directly linked with the process of fertilization, pollen producing capacity and anthers viability of pollen grains, pollen germination and pollen tube growth. Thus, number of seeds, number of pods and seed yield increased with B. The yield enhancement due to B application was also earlier reported by Verma *et al.* (2004).

5.3.3 Nutrient concentration and uptake

Nutrient concentration (N, P, K, S and B) and their uptake were studied at the time of harvest in grain and stover yields in mungbean. N concentration was higher in grain than in stover during both the years of the study. It was significantly influenced by the residual N, S and B in the soil although N sources were non-significant. The enhancement could be due to solubilizing effect of one nutrient upon the other as mentioned by Singh and Chauhan (2005).

The uptake followed the similar pattern during both the years. The uptake was higher with stover because the stover yield was much higher due to poor HI in pulses. Residual N application results in increased total N accumulation in component parts of the plant, nitrogenase activity, nodulation, total dry matter production and seed yield (Motior *et al.*, 1998).

5.3.3.2 P

P concentration was also higher in grain than stover due to quick remobilization towards grain at later stages. Even when the P concentration was higher, the total P uptake was more in stover due to its bulky nature. All the nutrients (N, S and B) applied produced good crop canopy hence aid to higher uptake by stover component.

5.3.3.3 K

K concentration followed the opposite trend and accumulated higher concentration in stover due to less mobilization towards grain. The K uptake was obviously higher in stover due to higher concentration and further higher dry matter accumulation by stover. Nutrients including N, S and B gave higher canopy development due to profuse vegetative growth, hence a relatively higher uptake was realized.

5.3.3.4 S concentration

S concentration was quite higher in grain than stover but still the uptake was higher with stover many fold due to earlier explained reasons of higher vegetative growth with S. N helped in enhancing S concentration as it is required for efficient use of S due to higher N concentration, the uptake of S was also higher. Application of S had a positive correlation with S concentration in plants. It has a significant effect on activities of catalase, absorbate peroxidase, gluacane peroxidase, synthesis of chlorophyll and active Fe content of green leaves which produce sink for S assimilation as also reported by Kumawat *et al.* (2006). N and S uptake (grain, stover and total) increased with increasing dose of N and S. The results were confirmed by Singh *et al.* (2001).

5.3.3.5 B

The concentration of B was slightly higher in grain than in the stover as B helped in cell wall formation, it is well trapped in the vegetative tissues as well. It regulates the N fixation also by an indirect effect. Growth of infection threads through root tissues bears a histological similarity to pollen tube growth through pistil tissues.

Growth of infection threads is arrested under B deficiency (Redonodo *et al.*, 2001). Hence B maintains overall nutrient balance. Since the concentration was very high in stover, the total uptake was also high in the stover.

5.3.4 Nutrient status of soil after sunflower-mungbean cropping system

Since mungbean is a legume crop, it has a characteristic feature of N fixation. The average amount of N fixed by mungbean varies from 20-25 kg/ha. This was the possible reason why the available N content of soil was higher after the harvest of the mungbean. Since it was grown to study the residual effect and no fertilizer was added, the amount of available P, K, S and B declined due to crop demand and uptake and losses by irrigation, rainfall, leaching or fixation. The impact was less on B and the decrease in B content was very less due to the fact that B is being continuously added to the soil through irrigated water and mungbean being a leguminous crop had some solubilization effects due to root exudates. The difference in available N status during the 2 years of the study could be because of the variable initial soil status of the nutrients.

5.3.5. Monetary returns from mungbean

Maximum returns were obtained by the application of S @ 50 kg/ha because S had the significant residual effect on growth and productivity of succeeding mungbean crop. The effect of N and B application was meager due to their leaching losses while S was retained more in the soil.

5.3.6. Monetary returns from the sunflower-mungbean cropping system

All the applied nutrients at different levels enhanced the net returns from the whole cropping system and S application @ 50 kg/ha resulted in the maximum enhancement due to its more requirement by both sunflower and mungbean.

SUMMARY AND CONCLUSIONS

Field experiments were conducted during spring and rainy (*kharif*) seasons of 2005 and 2006 on sunflower-mungbean cropping sequence at the research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi. The objectives set out for the study aimed at studying the effect of N sources, S and B levels on growth, yield attributes and yields and oil content and fatty acids composition of spring sunflower and its residual effect on succeeding mungbean crop in a sunflower-mungbean cropping system.

The design of experiment was factorial RBD for both sunflower and mungbean. A total of 19 treatments comprising 2 N sources *viz.* prilled urea and CAN; 3 levels of S *viz.* 0, 25 and 50 kgS/ha; 3 levels of B *viz.* 0, 0.75 and 1.5 and 1.5 kg B/ha and an absolute control were applied for sunflower crop and their residual effect on succeeding mungbean was studied. After statistical analysis the details of which are given in Chapter 3, all observations were recorded as per the methods mentioned in Chapter 3. The salient findings of this study are summarized in this chapter.

6.1. Effect of N sources, S and B levels on sunflower

6.1.1. Growth characters

1. The plant height increased at a higher rate during the period of 25 Days after sowing to 50 DAS. Application of N through different sources could not make much difference but different levels of S and B had a significant effect on plant height, dry matter accumulation followed the same pattern with the highest increase in leaf in the initial crop growth stages and in stem after 75 DAS. N sources were almost the same but S and B were highly correlated with increase in dry matter accumulation. Both the nutrients were more effective at their lower doses.
2. LAI increased substantially from 50-75 DAS with the highest values recorded at 75 DAS. Although N sources *i.e.* urea and CAN failed to make any

significant effect on LAI at any of the crop growth stages however, the levels of S and B were very effective to enhance the LAI. Not only the leaf spread but the total chlorophyll content also enhanced with different levels of S and B. The total chlorophyll content declined sharply at harvest stage. The highest chlorophyll content was observed with S application @ 50 kg/ha during both the years of the study.

3. Various growth parameters like CGR, RGR, NAR etc. were also enhanced due to fertilizer application since dry matter accumulation and leaf area were also influenced significantly. Although the values recorded were the highest for 2005, the trend followed was similar during 2006 also. CGR was maximum between 50-75 DAS while RGR and NAR were maximum during initial crop growth stage and declined thereafter. Maximum value for CGR was noticed at 1.5 kg B/ha while RGR and NAR were maximum with S application @ 50 kg/ha in 2005 and the values were maximum with B applied @ 1.5 kg/ha in 2006.

6.1.2. Yield attributes and yields

1. N, S and B application resulted in larger head size, higher number of seeds/capitulum, seed weight/capitulum and higher test weight during both the years, although the values were higher for 2005. Maximum values of almost all yield attributing characters were due to S application @ 50 kg/ha. B also enhanced all yield contributing characters, but the per cent increase was higher with 0.75 kg B/ha as compared to B applied @ 1.5 kg/ha.
2. Maximum seed yield was obtained with application of 1.5 kg B/ha, although S application also had a strong positive correlation with seed yield. Increase in the levels of S and B increased the seed yield during 2005 as well as in 2006. Two sources of N, i.e. urea and CAN proved to be almost same during 2006.
3. B application @ 1.5 kg/ha produced maximum stover and biological yields in 2005. Stover yield and total biological yield were more influenced by S in 2006. S application @ 50 kg/ha produced the highest stover yield and total biomass yield in 2006. A significant increase in stover yield was also noticed with B application; however, the per cent increase was much higher with B application @ 0.75 kg/ha as compared to B applied @ 1.5 kg/ha.

4. HI is the character which is comparatively less influenced by fertilization. N sources i.e. both urea and CAN absolutely failed to cause any significant impact and B application @ 0.75 kg/ha and 1.5 kg/ha produced HI statistically on par with each other. Here, S also could not influence HI reasonably and the values remained statistically at par with each other.

6.1.3. Quality parameters

1. Oil content was significantly influenced with fertilizer treatments. Relatively, a higher increase was recorded due to S and B application during both 2005 and 2006. In 2006, the content and oil yield were comparatively lower than 2005 but S was beneficial in enhancing the oil content as well as oil yield.
2. Protein content in seed was more increased due to N application. After N, more contribution for protein enhancement was made by B. B application @ 1.5 kg/ha produced seeds with the highest protein content during both the years of the study. S also had a significant effect but the effect was more pronounced at 50 kg S/ha.
3. Fatty acid composition of the sunflower seed revealed that N had a more significant effect in enhancing per cent of UFA and reducing SFA. The effect of S and B was quite meagre during both the years of study. S improved the oil quality further by enhancing iodine value and reducing the saponification value at 50 kg S/ha. Here B also affected these parameters significantly.

6.1.4. Concentration and uptake of nutrients

1. N concentration was recorded the maximum in leaf which declined from 25 DAS to till harvest stage. Roots observed less N concentration during both 2005 and 2006. At harvest stage, maximum concentration was recorded in seeds, less concentration was observed during 2006 while the uptake was maximum with leaves till 75 DAS and at harvest stage, seeds become the main sink. The highest uptake was recorded with either source i.e. urea or CAN.
2. P concentration was almost same during both the years and the concentration declined in both stem and leaves from 25 DAS to till harvest stage. Seeds recorded only maximum concentration of P followed by stem. The uptake was more throughout the life cycle except at harvest stage where seeds extracted maximum P. The uptake of P was maximum with B application @ 1.5 kg/ha.

3. K concentration followed a similar pattern during both the years. K concentration enhanced both in stem and leaves up to harvest stage. Seeds became important sink at harvest but its higher concentration was observed in vegetative parts. The uptake was also higher in stover than seeds during both the years of the study.
4. S concentration in different parts of sunflower at different growth stages diluted with advancement in growth stages. The concentration was higher in stem and it became the highest in seeds at harvest stage. Since S is more captured by seeds of sunflower, the uptake was also higher with S application @ 50 kg/ha followed by B applied @ 1.5 kg/ha.
5. B concentration was almost similar in leaf and stem initially and the ratio became wider at harvest. With the highest concentration in seeds, B application influenced the B distribution in plant parts. Initially more B uptake was recorded in leaves and later on in stem and finally the highest B uptake was recorded in seeds in both the years of the study.

6.1.5. Available nutrient status of soil after harvest of sunflower

1. Available nutrient status was mostly influenced on the upper layer up to 20 cm depth. Depending upon the initial status, the residual nutrients were more during 2005.
2. Available N decreased with increasing soil depth during the experimentation, while P, K, S and B increased in all the 3 depths of soil (0-20, 20-40 and 40-60 cm). The highest increase was noticed in N followed by S and B. Lower layers of soil were also enriched due to N, S and B application.

6.1.6. Monetary returns

1. Application of various nutrients enhanced the gross returns from sunflower crop than control although the increments were higher during 2005 than 2006. B application @ 1.5 kg/ha enhanced the gross returns to the maximum followed by S application @ 50 kg/ha.
2. N application found to be very beneficial for enhancing the net returns and B: C ratio. The increment was manifold higher when the source was urea than CAN. S application up to 50 kg/ha was beneficial, while B was also very economical

when applied @ 1.5 kg/ha with benefit: cost ratio 2.26 and 2.10 in 2005 and 2.07 and 1.98 during 2006, respectively.

6.2. Residual effect of nutrient management on succeeding mungbean crop

6.2.1. Growth parameters

1. Plant height and number of branches/plant were significantly influenced by application of different N source, S and B levels. N application to sunflower through CAN. produced taller mungbean plants with higher number of branches/plant which was grown as succeeding crop in sunflower-mungbean cropping system.
2. S and B levels also significantly influenced the biometric parameters of succeeding mungbean. S application @ 50 kg/ha produced the tallest plants and B application @ 1.5 kg/ha produced maximum number of branches/plant. The enhancement was more sharp at lower doses during both the years, although values were recorded higher for 2005.

6.2.2. Yield attributes and yields

1. Number of pods/plant and number of grains/pod were significantly higher than control when N, S and B were applied. N sources were not able to cause any significant difference but S and B levels brought an increment up to 30% in yield attributing characters. The enhancement noticed was more during 2005.
2. The highest grain and stover yield were observed with S application @ 50 kg/ha followed by B application @ 1.5 kg/ha. Out of the two N sources, CAN produced somewhat higher yields but the urea application remained statistically on par with CAN. The per cent increase was more in grain than stover during both the years of study. Change in harvest index was very less, although S application @ 50 kg/ha produced higher HI in 2005 only.

6.2.3. Nutrient concentration and their uptake

1. N and P concentration was noticed higher in the seed than stover but K concentration was observed higher in the stover during both the years of the study. A higher concentration and uptake of N, P and K was noticed due to the application of N, S and B. The increment was non-significant with both the sources of N but S application @ 50 kg/ha resulted in maximum concentration and uptake of N, P and K in almost all the plant parts of succeeding mungbean.

2. Similarly, S and B concentration were higher in the seed. The values were higher in 2005 but the uptake was comparatively higher in stover for both S and B. S application @ 50 kg/ha resulted in maximum uptake of S followed by B @ 1.5 kg/ha. For B maximum total uptake at harvest was noticed due to application of B @ 1.5 kg/ha.

6.2.4. Nutrient status of soil

1. Highest N status in soil was observed with S and B application and N status was even higher than the initial status at sowing of mungbean. P and K status remained almost similar, a little less than the initial figures. Both S and B failed to cause an effect in P and K status of soil, although it was higher for 2005 and 2006 than control.
2. S and B status of soil after mungbean was higher due to their different levels. Maximum residual S was seen with S @ 50 kg/ha in the preceding sunflower crop followed by 25 kg S/ha. Likewise, B found its maximum concentration with 1.5 kg/ha application and the status declined from the start of the crop.

6.2.5. Monetary returns from mungbean

1. Application of various nutrients enhanced the gross returns from succeeding mungbean crop than control and the increment was more during 2005.
2. N application was found to be beneficial through both CAN and urea while S application @ 50 kg/ha resulted in maximum returns and B: C ratio followed by B application @ 1.5 kg/ha.

6.2.6. Monetary returns from the sunflower-mungbean cropping system

1. N application through CAN proved to be less beneficial due to its higher cost than urea.
2. Out of the S levels, more returns were obtained up to 50 kg/ha, but the values were higher during 2005.
3. B application also had a positive effect to enhance the B: C ratio from 1.90 to 2.27 in 2005 and from 1.75 to 2.12 during 2006.

Conclusion

1. Application of various fertilizer treatments maintained their superiority in promoting overall growth parameters, yield attributes, yields and quality parameters of sunflower. Between two sources of nitrogen i.e. urea and CAN, CAN was found to be

superior than urea in terms of growth parameters, nutrient concentrations and their uptake by sunflower-mungbean cropping system.

2. Among the different levels of sulphur, the first dose i.e. sulphur @ 25 kg/ha was found to be more effective in terms of growth and yield and positive correlation was recorded up to 30-40 kg S/ha. Boron application @ 0.75 kg/ha and 1.5 kg/ha was very effective and the sunflower crop responded well up to the second dose. It also enhanced the total nutrient concentrations and their uptake by sunflower-mungbean cropping system and maintained a reasonably good available nutrient status of the soil.
3. Quality parameters including protein content and fatty acid composition were influenced more by nitrogen @ 80 kg/ha irrespective of the sources than sulphur and boron. Between the two nitrogen sources, urea proved to be superior than CAN in terms of net returns and benefit:cost ratio. The average economic optimum dose for sulphur remained between 35-40 kg/ha.
4. Nutrients applied to sunflower crop had a significant residual effect on the succeeding crop of mungbean in terms of growth parameters, yield attributes and yields. It also maintained the reasonably good available nutrient status of the soil after the harvest of the sunflower-mungbean cropping system in both the years of the experimentation.
5. If we quantify the influence of variable doses of sulphur and boron on growth, yield and nutrient uptake by sunflower, it can be concluded that the overall effect and influence on all the parameters was higher due to boron application. The efficiency factors were more due to boron application and it also enhanced the conversion efficiency of plant to divert photosynthates to the final yield components and yield.

Future line of research

Based on the present research findings carried out during 2005 and 2006 of sunflower-mungbean cropping system productivity, nutrient uptake and quality parameters as influenced by nitrogen sources, sulphur and boron levels, following important points can be suggested for the future thrust of research work to sustain the productivity of both the crops and quality of the soil.

- i. Instead of sources of nitrogen, it is suggested to take different levels of nitrogen through prilled urea instead of CAN since the cost of one kg of nitrogen through urea is one third of that of CAN.

- ii. Considering the faster growth of sunflower and high demand of sulphur for sunflower, it is suggested to have higher levels of sulphur through different sources viz., gypsum, ammonium sulphate, elemental sulphur and organic sources of sulphur like sulphonated press mud, to sustain the productivity and soil health. The study should be conducted for 3-4 cropping cycles in a system to see the residual effect i.e. immediate residual and cumulative residual on the succeeding mungbean crop.
- iii. After 3-4 years cropping cycle with suitable source of nutrient in appropriate amount at appropriate application time, a mathematical model can be fitted for more efficient use of inputs for trans-gangatic plains zone of northern India for sunflower-mungbean cropping system.

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Title of the thesis : **Effect of nitrogen sources, sulphur and boron levels on sunflower-mungbean cropping system**

ABSTRACT

A field experiment entitled “ Effect of nitrogen sources, sulfur and boron levels on sunflower-mungbean cropping system” was conducted during the spring and rainy season of 2005 and 2006 on a sandy loam soil, low in available N, medium in available P and high in available K at research farm of Indian Institute Agricultural Research, New Delhi. The experiment consisted of various nineteen treatment combinations including 2 sources of nitrogen; viz prilled urea and calcium ammonium nitrate (CAN), 3 levels of sulphur i.e. 0, 25 and 50 kg/ha and 3 levels of boron i.e. 0, 0.75 and 1.5 kg/ha were laid out in factorial randomized block design with 3 replications. The sunflower crop was grown on these treatment combinations in spring season whereas succeeding mungbean crop was grown on the residual fertility.

All the growth parameters like plant height, dry matter accumulation, CGR, RGR, and NAR were significantly influenced due to application of various treatments in all the plant parts of sunflower at different stages of crop growth. LAI and total chlorophyll content was also positively correlated with application of various nutrients especially N and sulphur. During both the years, a higher crop response was recorded at lower doses of nutrients applied. At higher doses the response became quadratic. S application @ 50 kg/ha produced higher changes in all growth parameters followed by B application @ 1.5 kg/ha. N sources failed to cause any significant impact on the growth parameters since urea and CAN both performed equally. Although the values were higher for CAN than urea and for the year 2005 than 2006.

Various yield attributing characters and yield were recorded significantly higher due to various treatments. The most effective nutrient proved was S followed by B and N. N sources were found to be at par with each other during both the years. S application @ 50 kg/ha produced an abrupt change in all the parameters and the rate of the response declined at 50 kg/ha although the values were numerically higher at this dose. B was also able to cause an increase in seed yield at higher rate, also in the stover and total biological yield, but the rate of increment was lower. Harvest index was a less influenced character but still S and B had a marked effect, maximum values were hence recorded with S @ 50 kg/ha.

Quality parameter like oil content is also influenced with various fertilizer treatments. During both the years, S had a dominant effect over B to enhance the oil content and a steady increase was noticed with increasing S doses. Protein content was more influenced with N application. N had a direct effect in increasing protein content, although S application @ 50 kg/ha produced maximum protein content in the seeds of sunflower. The effect of B was seen more sharply at 0.75 kg/ha application. Fatty acid composition was also altered due to change in nutrient application. N and S were potential enough to increase unsaturated fatty acid and decrease the content of saturated fatty acid to enhance the keeping quality of the oil.

Nutrient concentrations in different plant parts at different crop growth stages were in the accordance with the nutrient supply. When N, S and B were supplied, then concentration increased in all plant parts. Different nutrients not only affected their own

concentration in the plant, but also influenced other nutrient's concentration as well positively and significantly. At harvest stage, all nutrient concentrations were recorded maximum in seeds except K. The uptake of various nutrients was in line with their concentrations in the plant parts and their respective dry matter accumulation.

The economic studies revealed that the application of various nutrients enhanced the economic returns from the crop. N, S and B application proved to be very beneficial but N source i.e. urea was very economic than CAN with almost double B:C ratio. S application proved to be more economic up to 25 kg S/ha. B application @ 0.75 kg/ha gave the highest B:C ratio and the ratio declined at the subsequent higher dose.

If we quantify the influence of variable doses of sulphur and boron on growth, yield and nutrient uptake by sunflower, it can be concluded that the overall effect and influence on all the parameters was higher due to B application. The efficiency factors were more due to B application and it also enhanced the conversion efficiency of plant to divert photosynthates to the final yield components and yield

The residual effect of nutrient application in the sunflower had a clear effect on the succeeding mungbean crop in terms of biometric parameters, yield attributing characters and the final yield. Maximum seed yield was produced where S application in the preceding crop was @ 50 kg/ha, it had a good amount of residue left in the field than N. the uptake was also higher for N, S and B as they were applied in the previous season. The soil status also enhanced in terms of different nutrients, especially N.

It might be concluded that sunflower being a rich oil crop, which responded very well to the applied fertilizers. N, S and B are the most important elements for sunflower crop for increased productivity and quality produce. Urea as a source of N was very effective along with S application @ 30-40 kg/ha and B @ 1.5 kg ha⁻¹ which produced higher growth parameters, yield attributes and yield, with enhancement in concentration and uptake of various nutrients. It also produced a quality crop with a good soil fertility status left after the cropping sequence.

सूरजमुखी-मूंगबीन फसल प्रणाली पर नाइट्रोजन स्रोतों, सल्फर तथा बोरोन स्तरों का प्रभाव

सारांश

“सूरजमुखी-मूंगबीन फसल प्रणाली पर नाइट्रोजन स्रोतों, सल्फर तथा बोरोन स्तरों का प्रभाव” विषय पर 2005 तथा 2006 के बसंत एवं वर्षा मौसम के दौरान भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली के अनुसंधान फार्म पर रेतीली दुम्मटी मिट्टी, भिन्न नाइट्रोजन उपलब्धता, मध्यम फास्फोरस उपलब्धता तथा K की उच्च उपलब्धता के साथ खेत परीक्षण आयोजित किया गया। परीक्षण में विभिन्न 19 उपचार संयोजनों सहित नाइट्रोजन के 2 स्रोत यथा प्रिल्ड यूरिया तथा कैल्शियम अमोनियम नाइट्रेट (CAN), सल्फर के 3 स्तर जैसे 0, 25 तथा 50 कि.ग्रा./है. और बोरोन के तीन स्तर यथा 0, 0.75 एवं 1.5 कि.ग्रा./है. को 3 प्रतिकृतियों के साथ क्रमगुणित यदृच्छिक ब्लॉक डिजाइन में स्थापित किया गया। सूरजमुखी फसल इस उपचार संयोजनों के साथ बसंत मौसम में उगायी गयी। जबकि इसके बाद मूंगबीन फसल को शेष उर्वरता पर उगाया गया।

फसल बढ़वार की विभिन्न दशाओं में सूरजमुखी पौधे में सभी हिस्सों में विभिन्न उपचार अनुप्रयोग के कारण पादप ऊंचाई, शुष्क सामग्री संचयन, CGR, RGR तथा NAR जैसे वृद्धि पैरामीटरों में उल्लेखनीय प्रभाव पड़ा। विभिन्न पोषक तत्वों विशेषकर N तथा सल्फर के अनुप्रयोग के साथ LAI तथा कुल क्लोरोफिल मात्रा भी सकारात्मक रूप में संबंधित थी। दोनों वर्षों के दौरान, पोषक तत्वों की अल्प मात्रा में उच्च फसल प्रतिक्रिया दर्ज की गयी। उच्च मात्रा प्रयोग से प्रतिक्रिया द्विघाती बन गई। 50 कि.ग्रा./है. की दर से सल्फर अनुप्रयोग के बाद 1.5 कि.ग्रा./है. बोरोन अनुप्रयोग करने से सभी वृद्धि पैरामीटरों में अधिक बदलाव उत्पन्न हुए। चूंकि यूरिया तथा CAN दोनों का प्रदर्शन समान था, नाइट्रोजन स्रोत वृद्धि पैरामीटरों पर कोई विशिष्ट प्रभाव छोड़ने में असफल रहे। हालांकि यूरिया की तुलना में CAN के लिए तथा 2006 के मुकाबले वर्ष 2005 के लिए मान कहीं अधिक थे।

विभिन्न उपचारों के कारण भिन्न उपज गुण विशेषता और पैदावार में उल्लेखनीय वृद्धि दर्ज की गई। सबसे अधिक प्रभावी पोषक तत्व सल्फर सिद्ध हुआ जबकि बोरोन तथा नाइट्रोजन का नंबर इसके बाद कमशः था। दोनों वर्षों के दौरान नाइट्रोजन स्रोत का प्रभाव एक समान पाया गया। 50 कि.ग्रा./है. सल्फर अनुप्रयोग से सभी पैरामीटरों में आकस्मिक परिवर्तन देखा गया तथा

प्रतिक्रिया दर में 50 कि.ग्रा./है. की गिरावट आई हालांकि इस मात्रा के प्रयोग में अंकों के हिसाब से मान ज्यादा थे। बोरोन उच्चदर पर बीज पैदावार स्टोवर में भी तथा कुल जैविक पैदावार बढ़ाने में सक्षम था लेकिन अभिवृद्धि की दर निम्न थी। कटाई सूचकांक एक निम्न प्रभावी गुण था लेकिन सल्फर तथा बोरोन अपना प्रभाव छोड़ने में कामयाब रहे। 50 कि.ग्रा./है. की दर से सल्फर प्रयोग से अधिकतम मान दर्ज किये गए। विभिन्न उर्वरक उपचारों के साथ तेल मात्रा जैसे क्वालिटी पैरामीटर भी प्रभावित होते हैं। दोनों वर्षों के दौरान बोरोन के मुकाबले सल्फर का प्रदर्शन तेल मात्रा बढ़ाने में कहीं अधिक प्रबल था और बढ़ी हुई सल्फर मात्रा के साथ लगातार वृद्धि दर्ज की गई। नाइट्रोजन अनुप्रयोग के साथ प्रोटीन स्तर अधिक प्रभावित हुआ नाइट्रोजन का प्रोटीन मात्रा बढ़ाने में सीधा प्रभाव था हालांकि 50 कि.ग्रा./है. की दर से सल्फर अनुप्रयोग के द्वारा सूरजमुखी के बीजों में अधिक प्रोटीन मात्रा उत्पन्न हुई। 0.75 कि.ग्रा./है की दर से बोरोन अनुप्रयोग प्रभाव में अधिक तीव्रता पाई गई। पोषक तत्वों से अनुप्रयोग में बदलाव के कारण वसा अम्ल संयोजन में भी बदलाव देखा गया। तेल की वर्तमान गुणवत्ता को बढ़ाने के लिए नाइट्रोजन तथा सल्फर असंतृप्त वसा को बढ़ाने और संतृप्त वसा अम्ल की मात्रा घटाने में सक्षम थे।

फसल की विभिन्न बढ़वार दशाओं में पौधे के विभिन्न हिस्सों में पोषक एकाग्रता फसल को पोषक तत्वों की आपूर्ति के अनुसार थी। जब नाइट्रोजन, सल्फर तथा बोरोन की आपूर्ति की गई तब पौधे के सभी हिस्सों में पोषक एकाग्रता बढ़ी। विभिन्न पोषक तत्व न केवल पौधे में अपनी एकाग्रता प्रभावित करते हैं वरन् अन्य पोषक तत्वों की एकाग्रता पर सकारात्मक एवं उल्लेखनीय प्रभाव डालते हैं। कटाई स्तर पर, केवल K को छोड़कर सभी पोषक तत्वों की एकाग्रता बीजों में अधिकतम दर्ज की गई। पौधे के हिस्सों में तथा संबंधित शुष्क पदार्थ संचयन में अपनी एकाग्रता के अनुसार ही विभिन्न पोषक तत्वों की ग्राह्यता थी।

आर्थिक अध्ययन से पता चलता है कि विभिन्न पोषक तत्वों के अनुप्रयोग से फसल से प्राप्त होने वाली आमदनी में वृद्धि होती है। नाइट्रोजन, सल्फर तथा बोरोन अनुप्रयोग बहुत लाभदायक सिद्ध होगा लेकिन नाइट्रोजन स्रोत यथा यूरिया लगभग दुगने अनुपात B:C के साथ CAN की तुलना में बहुत अधिक लाभदायक था। 25 कि.ग्रा. सल्फर/है. तक सल्फर अनुप्रयोग कहीं अधिक लाभदायक होगा। 0.75 कि.ग्रा./है. की दर से बोरोन के अनुप्रयोग से उच्चतम B:C अनुपात हासिल हुआ तथा इसके बाद अनुप्रयोग की मात्रा बढ़ाने पर अनुपात में कमी आई।

यदि हम सूरजमुखी में वृद्धि, पैदावार और पोषक तत्व ग्राह्यता पर सल्फर और बोरोन की विभिन्न मात्रा के प्रभाव को निर्धारित करें तो निष्कर्षतः यह कहा जा सकता है कि बोरोन अनुप्रयोग के कारण सभी पैरामीटरों पर समग्र प्रभाव ज्यादा था। बोरोन अनुप्रयोग के कारण प्रभावशीलता

कारक कहीं अधिक थे और इससे पौधे में अंतिम पैदावार अवयव और पैदावार के लिए प्रकाश संश्लेषण को परिवर्तित करने की पौधे की प्रभावशीलता भी बढ़ी।

सूरजमुखी में पोषकता अनुप्रयोग के अवशेष प्रभाव से अनुवर्ती मूंगबीन फसल में बायोमेट्रिक पैरामीटरों, उपज विशेषताओं और अंतिम पैदावार के संबंध में स्पष्टतः असर था। अनुवर्ती फसल में जहां कहीं 50 कि.ग्रा./है. की दर से सल्फर अनुप्रयोग किया गया वहां अधिकतम बीज पैदावार उत्पन्न हुई, इससे खेत में नाइट्रोजन की तुलना में कहीं अधिक अवशेष मात्रा रही, पूर्व मौसम में किए गए अनुप्रयोग की तुलना में नाइट्रोजन, सल्फर तथा बोरॉन के लिए ग्राह्यता भी अधिक थी। विभिन्न पोषण विशेषकर नाइट्रोजन के संबंध में मृदा स्थिति में भी सुधार हुआ।

यह निष्कर्ष निकाला जा सकता है कि सूरजमुखी एक समृद्ध तिलहन फसल होने के कारण प्रयुक्त होने वाले उर्वरकों के प्रति बहुत अधिक उत्तरदायी है। उत्पादकता और क्वालिटी उत्पाद बढ़ाने के लिए सूरजमुखी फसल हेतु नाइट्रोजन, सल्फर तथा बोरॉन बहुत महत्वपूर्ण अवयव हैं। 30-40 कि.ग्रा./है. की दर से सल्फर तथा 1.5 कि.ग्रा./है. की दर से बोरॉन अनुप्रयोग के साथ नाइट्रोजन के स्रोत के रूप में यूरिया का प्रयोग अत्यधिक प्रभावी था जिससे विभिन्न पोषक तत्वों की ग्राह्यता एवं एकाग्रता में वृद्धि के साथ उच्चतर वृद्धि पैरामीटरों, उपज विशेषताओं तथा पैदावार में वृद्धि हुई। इससे फसल अनुक्रमण छोड़ने के बाद भी बेहतर मृदा उर्वरता स्थिति के साथ क्वालिटी फसल उत्पन्न हुई।

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